National Defence | Défense nationale

GAIN MEASUREMENT OF A CAVITY-BACKED SPIRAL ANTENNA FROM 4 TO 18GHz USING THE THREE-ANTENNA METHOD

by

Claude J. Brochu, Gilbert A. Morin
and John W. Moffat

DEFENCE RESEARCH ESTABLISHMENT OTTAWA

REPORT NO. 1337

Canada

November 1998
Ottawa

National Defence Défense nationale

GAIN MEASUREMENT OF A CAVITY-BACKED SPIRAL ANTENNA FROM 4 TO 18GHz USING THE THREE-ANTENNA METHOD

by

Claude J. Brochu, Gilbert A. Morin and John W. Moffat

Milsatcom Group

Space System & Technology Section

DEFENCE RESEARCH ESTABLISHMENT OTTAWA

REPORT NO. 1337

PROJECT
5CA12

November 1998
Ottawa

ABSTRACT

This report presents the results of the measurement of the maximum gain of a cavity-backed spiral antenna in the frequency range of 4-18 GHz. This measurement activity was requested by CFEWC. The method selected for this measurement was the three-antenna method for antenna gain measurements. As the antenna-under-test (AUT) is a circularly polarized (CP) antenna, the method was extended to obtain the CP co-pol and cross-pol gain of the AUT. This method requires the use of two other linearly polarized (LP) antennas. Two sets of gain measurements were performed using the LP antennas with their polarization oriented horizontally and then vertically. The two antennas were TECOM LP quad-ridged horns. Although these horns are dual polarized, only one polarization was used. This report describes also the three-antenna method algorithm, the Matlab program written for this application, and gives an outlook of the experimental steps and procedures required to implement the method.

The antenna gain measurements were made in the far-field antenna measurement range in the DREO-DFL Antenna Research Laboratory (DDARLing).

RÉSUMÉ

Ce rapport présente les résultats de mesures de gain d'une antenne à cavité en spirale qui opère dans la plage de fréquence de 4 à 18 GHz. Ces mesures d'antennes, requises par le CFEWC, ont été effectuées en se servant de la méthode de mesure de gain à trois antennes. Comme l'antenne à tester était polarisée circulairement, la méthode fut étendue pour obtenir les gains à polarisation circulaire copolaire et contrapolaire. Cette méthode requiert l'emploi de deux autres antennes ou cornets à polarisation linéaire. Deux sessions de mesures de gains ont été nécessaires afin de mesurer les composantes horizontales et verticales du gain. Les deux antennes choisies étaient des cornets à quadruples cloisons linéairement polarisés de marque TECOM. Quoique ces cornets soient configurés pour une double polarisation, seulement une des polarisations a été utilisée. Ce rapport décrit en plus la méthode des trois antennes donnant une explication détaillée de l'algorithme de calcul, une description du programme Matlab spécialement développé pour cette application, et un aperçu des étapes expérimentales à employer pour effectuer les mesures.

Ces mesures de gains d'antennes ont été accomplies au moyen du système de mesure d'antennes à champ éloigné du laboratoire de recherches sur les antennes du CRDO-LDF (DDARLing).

EXECUTIVE SUMMARY

This report presents the results of the measurement of the maximum gain of a cavity-backed spiral antenna in the frequency range of 4-18 GHz. This measurement activity was requested by the Canadian Force Electronic Warfare Center (CFEWC). Absolute gain measurement techniques were employed for this measurement. This was done using a method called the three-antenna method for antenna gain measurements. This will allow for very precise measurement of gain. The on-axis gain of the circularly polarized (CP) cavity-backed spiral antenna has been measured using this method. The CP co-pol gain of this antenna has been found to vary between 2.2 and 5.8 dB in the frequency range of 4-18 GHz, with the polarization sense being left hand circularly polarized (LHCP). This absolute gain measurement technique employs the measurement of the signal using three antennas taken 2-by-2 and involves solving the three simultaneous transmission equations resulting from the measurements of the three antenna-pairs.

The purpose of this report is two-fold: firstly, the reporting on the gain measurement of the antenna-under-test (AUT), and secondly, which is most important, the presentation and detailed mathematical description of the three-antenna method for measuring the absolute gain of an antenna. The method was implemented into a Matlab program and a brief outlook of the experimental steps and measurement procedures required to implement the method is also presented.

The Matlab program permits the gain computation of an AUT, which may be linearly (LP), or circularly polarized, using two other LP antennas. The data input requirements for the program (such as the input parameters and the measured data files) and the data output generated (such as the output graphs and the disk file of calculated gains) are also described.

For an LP AUT, three antenna-pair measurements are required to calculate the LP co-pol gain. The LP cross-pol gain is not measured or calculated. For a CP AUT, two sets of three antenna-pair measurements are required, i.e. one set for the probes oriented horizontally and a second set for the probes oriented vertically. In the CP AUT case, more processing is therefore required to obtain the partial gains and to calculate the required co-pol and cross-pol gains, relative or absolute. A double graph is generated to display the gains. Moreover, some user interaction with the graphs is implemented to modify titles, subtitles, location of the legends and date.

Finally, a listing of the program is provided in Appendix A.

TABLE OF CONTENTS

ABSTRACT iii

RÉSUMÉ iii

EXECUTIVE SUMMARY v

TABLE OF CONTENTS vii

TABLE OF ILLUSTRATIONS ix

1. Introduction 1

2. The Far-Field Measurement System 1

3. Methodology of the Measurement of the Gain of Antennas 3

4. Absolute Gain Calculation or the Three-Antenna Gain formulation 4

5. Matlab Program for Gain Calculation – *gain3ant* 8

6. Measurement of gain of the AUT 14

7. Conclusion 21

References 23

Appendix A - Matlab Program *"gain3ant"* Listings 25

  gain3ant 26

  getparam 35

  gain3acalc 37

  freqchk 41

  wi_read 42

  Function ascanf 46

TABLE OF ILLUSTRATIONS

Figure 1. Test Setup for Measuring Antenna Gain 3

Figure 2. Test configuration for the three-antenna method of gain determination 4

Figure 3. Openning Help Window 10

Figure 4. *gain3ant* Program Usage Showing Input requirements and Output Generation 12

Figure 5. Measurement of Leakage with Transmit Chain Terminated at the AUT. 16

Figure 6. Attenuation of HP 8495D Step Attenuator, All Steps 16

Figure 7. Attenuation of HP 8495D Step Attenuator, All Steps 17

Figure 8. Experimental Setups and procedures for the Three-Antenna Gain Measurement Method 18

Figure 9. Circularly Polarized AUT Gain 19

Figure 10. Matlab Workspace Program Output and Data File Header Examples 20

1. Introduction

During 1997, the Canadian Force Electronic Warfare Center (CFEWC) requested that the gain of an antenna be measured at the DREO-DFL Antenna Research Lab (DDARLing). Little information was released about the antenna to be tested except that it was a circularly polarized (CP) cavity-backed spiral antenna operating in the 4 to 18 GHz range. It was requested that the CP gain characteristics of the antenna be measured.

Two general methods[1] exist to measure the gain of an antenna. They are the gain-transfer measurements and absolute gain measurements. In gain-transfer measurements, the gain of the antenna-under-test (AUT) is determined by comparing the signal that is received when the AUT is used in the circuit to that which is received when a standard gain horn (or other calibrated antenna) is used in its place. This is the simplest method, and requires little computation. The absolute gain measurement techniques usually employ the measurement of the signal using a number of antennas and solving simultaneous transmission equations. The usage of absolute gain techniques allow for very precise measurement of gain, but the utmost attention must be given to obtaining a proper test environment and to processing the errors from various sources to insure the measured gain is indicative of the true gain of the antenna[2]. In this case, the on-axis gain of an antenna has been determined within approximately 0.1 dB at the National Institute of Standards and Technology (NIST), Boulder, CO.

For our measurement, it was decided to employ absolute gain measurement techniques using a method called the three-antenna method for gain measurement. Two dual-polarized quad-ridged horns, operating in the same frequency range, were available for the gain measurement.

This report describes the setup of the lab for the measurements, a description of the three-antenna method algorithm, the MATLAB program developed for its implementation, and the results that were obtained.

2. The Far-Field Measurement System

The wave radiated from an antenna is spherical in nature. As the distance from the antenna is increased, the curvature of this spherical wave over a specific planar capture area decreases, resulting in an apparent local flattening of the wave. At an infinite distance, this wave will appear as a plane wave. This means that, at this distance, if a small receiving antenna (probe) were to be moved over this planar capture area, it would measure a constant phase in the signal received from the AUT. There will be a distance, however, where the wave is close enough to being planar that these phase variations will be small and the wave can be said to approximate a plane wave. At this point, it is said that the probe antenna is in the far field of the AUT. The fields produced by an antenna are of three types, depending on the distance from the aperture. These are the reactive near field, the radiating near field, and the radiating far field. The reactive near-field region, also referred to as the evanescent region, extends out to about 10 wavelengths. No power is propagating in this wave, as it is comprised of stored energy only. There is power propagating in the radiating near field, and it can be measured using field probes, except that it does not yield the same antenna field pattern as when the radiating far field is measured.

The radiating near-field region, or simply near-field region[3], is normally defined as the region extending from the evanescent region to a point on the axis of the antenna at a distance where the difference in the path lengths from that point to the center of the antenna and to the edge of the antenna is 22.5 degrees ($\lambda/16$) at the frequency in question. This assumes that the antenna that is measuring the field of the AUT is very much smaller than it is, or is infinitesimally small. This distance from an antenna to the far edge of the near-field region of that antenna is calculated with the equation $r = 2d^2/\lambda$, where d is the diameter of the antenna and λ is the wavelength, all dimensions being in the same units. In the case of two antennas facing each other, if each is to be in the far-field of the other, the minimum separation of the two antennas would be the sum of the far-field distances, $r = 2(d_1^2 + d_2^2)/\lambda$ where d_1 and d_2 are the dimensions of the two antennas. If one antenna is much smaller than the other is, then the distance to the far field will be dominated by the size of the larger antenna. Also, because the lower gain antennas are usually smaller, the distance to the far field is shorter and they may be able to be measured on the far-field range with the field probe antenna at a sufficient distance to be in the far field, thus obtaining accurate measurements.

In DDARLing, two antenna measurement ranges exist. These are the far-field and the near-field ranges. For the purpose of gain measurement as described in this report, the far-field range was used. The far-field range is contained in a shielded anechoic chamber that measures 5.8x3.3x3.3m^3. The microwave absorber used in the chamber is pyramidal shaped carbon-impregnated foam, the cones each measuring 45 cm from the tips to the bottom of the base. Measurements can be made in the frequency range of 2.0 to 62.5 GHz. Two antenna towers are provided. A roll-over-azimuth configuration is used for the AUT that allows the measurement of the energy radiated from the antenna over a wide range of angles. A roll positioner is used to support the probe antenna. All the positioners were manufactured by Orbit Advanced Technologies Ltd. The reader will find a more complete description of the far-field system in the DDARLing laboratory at reference 4 and 5.

The set-up of the receiver in the far-field range is shown in Figure 1. The Wiltron 360B Vector Network Analyzer (VNA) controls the 3622A Active Device Test Set and the 360SS69 RF Sweeper through the General Purpose Instrument Bus (GPIB). The VNA contains the displays and can be used to control the sweeper and test set locally, or by computer control. Since these measurements were single measurements, they were easily done manually, without the aid of a computer to control the VNA and log the data.

The measurements were taken using a frequency sweep of 500 frequency points in the measurement frequency range. The measured data in the VNA were saved to diskettes and transferred to a personnel computer for later post-processing and gain calculation using a Matlab program.

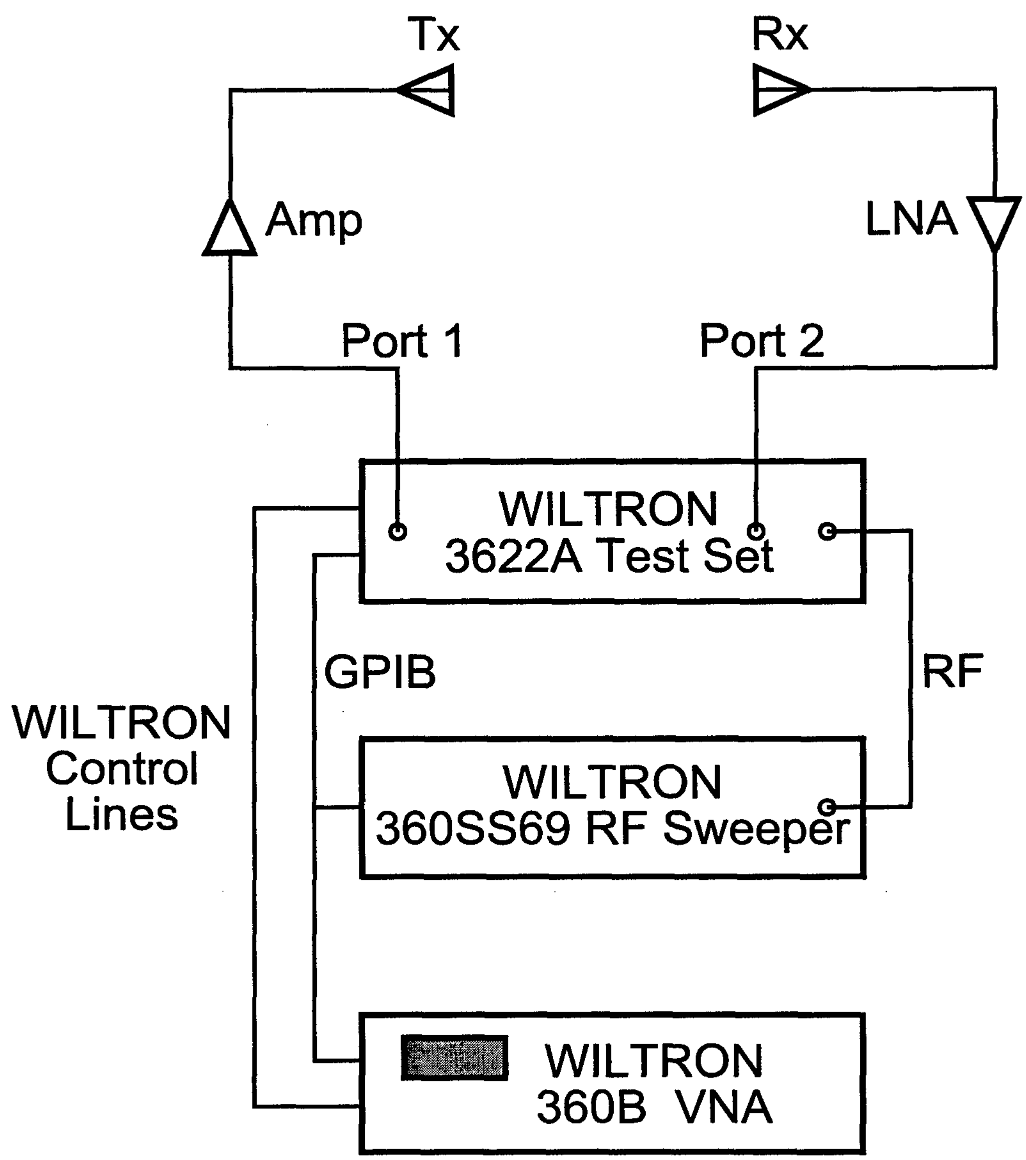

Figure 1. Test Setup for Measuring Antenna Gain

3. Methodology of the Measurement of the Gain of Antennas

The three-antenna method for gain calculation permits an accurate characterization of the gain of the AUT and also of the gain of the other two antennas as well. Special attention has to be given to accuracy in the various measurements, because many sources of errors are involved. These individual error sources in themselves may be quite small, but when combined may result in an error incompatible with the accuracy desired. Because the measurements are done inside an anechoic chamber, most of the errors are eliminated or at least greatly diminished. The following considerations contribute to a test environment compatible with the measurements to be made. The absorbers lining the ceiling, walls and floor, and covering equipment and apparatus reduce reflections from surrounding objects to an acceptable level and mask RF leakage from circuitry, thus reducing multipath and leakage effects to a minimum. The fact that the antenna support system is aligned optically with great precision brings both test antennas to the same level and at a sufficient height. This reduces the problems associated with measuring their separation precisely. The test range is of sufficient length to adequately minimize interaction between antennas. This permits the calculation of the gain to be as close as possible to the true gain with an acceptable error associated with these additive error factors.

In implementing the three-antenna method for gain calculation, the antenna to be measured was set at one end of the range and pointed at the receiving antenna (probe). The pointing directions were adjusted so the received signal was maximized. Because the spherical far-field system is well aligned, two antennas are aligned on the same axis with only minor adjustment required to maximize the signal. A recording of the signal was then made. The probe was then changed for the third antenna and the received signal again recorded(2). Finally, the AUT was changed for the first probe, the probe pointing direction adjusted for maximum received signal, and the received signal of the third antenna pair was again recorded. As explained later in the next section, two other (calibration) measurements were recorded to evaluate a correction term to the gain calculation formula. These measurements, the *Cable-Thru* correction and the attenuator frequency response measurements *Atten*, were used to calibrate the gain by measuring the RF chain insertion loss between the antennas and the VNA.

4. Absolute Gain Calculation or the Three-Antenna Gain formulation

The absolute gain is calculated using the Friis transmission formula for power transfer between antennas(2). Consider two antennas A and B separated by a distance R_{AB} as seen in Figure 2. The power transfer between the two antennas is given by equation (1):

$$P_r = P_o G_A G_B \left(\frac{\lambda}{4\pi R_{AB}} \right)^2 \qquad (1)$$

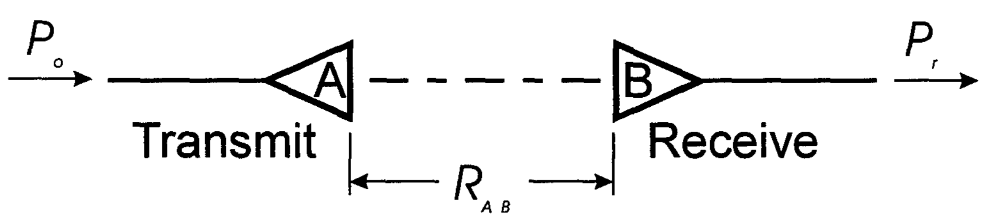

Figure 2. Test configuration for the three-antenna method of gain determination

The Friis formula is based on the assumption that the antennas are polarization matched, located in free space, and separated sufficiently that there is negligible interaction between them, and that plane wave condition exists.

It is convenient to convert the Friis formula to the decibel notation to simplify its application. The formula is written in logarithmic form as

$$G_{A-dB} + G_{B-dB} = 20Log_{10}\left(4\pi R_{AB}/\lambda\right) + 10Log_{10}\left(P_r/P_o\right) \qquad (2)$$

In the above equation,

$G_{A\text{-}db}$ = maximum gain of antenna A in dB = $10\ Log_{10}\ G_A$

$G_{B\text{-}db}$ = maximum gain of antenna B in dB = $10\ Log_{10}\ G_B$

R_{AB} = separation distance in meters between both antennas

λ = wavelength of the transmitted wave in meters

P_o = signal level at the input terminals of the transmitting antenna

P_r = signal level at the output terminals of the receiving antenna

$G_{A\text{-}db}$ and $G_{B\text{-}db}$ are the maximum gains of the antennas. The equation is valid as long as the separation distance between the antennas is large enough that the wave illuminating the receiving antenna is a plane wave of uniform amplitude, i.e. the separation distance is large enough for both antennas to be in the far-field. The greater the distances between these antennas, the more closely these gains approximate the true gain of the antenna.

In the three-antenna method for gain measurement, a third antenna C replaces antenna B and the measurements are repeated. This results in a second equation similar to equation (2) but which relates to the gains of the antennas A and C. A third set of measurements is then made between the antennas B and C and a third equation is obtained.

The magnitude of the power ratio in the right term of equation (2) is measured directly by a Vector Network Analyser; it is the *S21* S-parameter transmission term. As the terms P_o and P_r of the equation represent the power at the antenna terminals and, as *S21* is a measurement of the power ratio between port 2 and port 1 of the VNA, correction terms must be added to the equations. This correction will take into account the gains of amplifiers and insertion losses of cables and devices in the transmission and receiving chains, linking the VNA to the antennas. This must be taken into account separately, however. The correction terms are acquired by doing, at the frequencies of interest, separate measurements of the complete RF chains without the antennas (*Cable-thru* correction measurements), by removing the antennas from the RF chain and physically joining the transmitting and receiving circuitry. When additional components such as cables to close the circuit and attenuators to adjust the RF levels at the low noise amplifier (LNA) are added to the circuit, a second set of separate measurements, the calibrated frequency response of the attenuator (*Atten*) is also required. The correction term to be included in the power transfer equation is calculated as

$$Correction = Cable\text{-}thru\ -\ Atten$$

The three modified equations are of the form

$$G_{A-dB} + G_{B-dB} = FactorAB - Correction$$

$$G_{A-dB} + G_{C-dB} = FactorAC - Correction$$

$$G_{B-dB} + G_{C-dB} = FactorBC - Correction$$

In the equation below, *FactorAB* is expanded with λ = *.3/F* where λ is the wavelength in meters and F is the frequency in GHz. A similar expansion is also done for the other two Factor terms.

$$FactorAB = 20Log_{10}(4\pi R_{AB}F/.3) + S21_{AB}$$

Solving the equations to get the gain of the three antennas, one obtain

$$G_{A\text{-}dB} = \tfrac{1}{2}\,(FactorAB + FactorAC - FactorBC - Correction)$$

$$G_{B\text{-}dB} = \tfrac{1}{2}\,(FactorAB + FactorBC - FactorAC - Correction)$$

$$G_{C\text{-}dB} = \tfrac{1}{2}\,(FactorAC + FactorBC - FactorAB - Correction)$$

When the three antennas are linearly polarized, the three gains are calculated with the above relations. However, if the test antenna (AUT) is not linearly but circularly polarized (CP), extra gain measurements are required to take into account the power radiated in orthogonal polarizations, vertical and horizontal. The other two antennas, therefore, must be linearly polarized in order to perform these two partial gain measurements of the CP AUT. These measurements are an important step in the determination of the CP gain of the AUT. The partial measurements measure the total power of the wave radiated by the test antenna, which is contained in the two linear orthogonal components. The first measurement procedure (using the three-antenna method) is done orienting the two LP antennas horizontal to measure the gain G_{H-dB} for the horizontal polarization. The procedure is then repeated for the vertical polarization to measure the gain G_{V-dB}. The linear sum of the two partial gains represents the total gain G_T of the CP AUT. The equations (3 to 5) below calculate the total gain. Because the partial gains resulting from the three-antenna formulas are in decibels they must first be transformed to their power ratio form with the following anti-log formula.

$$G_H = 10^{\left(\frac{G_{H-dB}}{10}\right)} \qquad (3)$$

and

$$G_T = G_H + G_V \qquad (4)$$

In decibels the relation becomes

$$G_{T-dB} = 10Log_{10}G_T \qquad (5)$$

The specific gains, which must be measured, however, are the CP co-pol gain and cross-pol gain of the AUT. Therefore, extra processing must still be performed to obtain these gains. The relation below expresses the CP co-pol gain of the AUT as a function of the total gain and the CP relative cross-pol gain X_{CP}^{rel}.

$$G_{CP} = \frac{G_T}{1 + X_{CP}^{rel}} \qquad (6)$$

In decibels the CP co-pol gain relation becomes

$$G_{CP-dB} = 10Log_{10}G_{CP}$$

and the CP cross-pol gain is

$$X_{CP-dB} = G_{CP-dB} + X_{CP-dB}^{rel}$$

The CP relative cross-pol gain X_{CP}^{rel}, introduced in equation (6), is required for the transformation of the total gain into the CP co-pol gain. For its determination, the magnitude and phase information of a measurement pair of antennas such as the AUT with one of the other two antennas is required.

The following relationships must be established. In the equations (7 to 10) below, the R and L subscript index in the variable names refer to the right and left sense of the CP, and the H and V subscript refer to the horizontal or vertical component of the polarization.

$$E_R = \frac{1}{\sqrt{2}}(E_H + jE_V)$$
$$E_L = \frac{1}{\sqrt{2}}(E_H - jE_V) \qquad (7, 8)$$

E_H and E_V represent the complex value of the measurement data and are calculated as below

$$E_H = 10^{\frac{M_H}{20}} e^{j\left(\frac{\varphi_H \pi}{180}\right)}$$
$$E_V = 10^{\frac{M_V}{20}} e^{j\left(\frac{\varphi_V \pi}{180}\right)} \qquad (9, 10)$$

where M and φ relate to the magnitude in dB and to the phase in degrees as measured by the VNA.

The co-pol and cross-pol signals E_{co} and E_x in CP must be assigned by analysing the magnitude of the right and left E fields. Usually $|E_{co}| > |E_x|$ so,

$E_{co} = E_R$, $E_x = E_L$, if $|E_R| > |E_L|$ or

$E_{co} = E_L$, $E_x = E_R$, if $|E_L| > |E_R|$

The relative cross-pol X_{CP}^{rel} is defined as

$$X_{CP}^{rel} = \left|\frac{E_x}{E_{co}}\right|^2$$

In decibels, the relation becomes

$$X_{CP-dB}^{rel} = 10 Log_{10} X_{CP}^{rel}$$

The sense of the circular polarization can be resolved by analysis of the fields calculated as above in equations 7 and 8. The sense of the CP is denoted ***RHCP*** for right-hand circular polarization or ***LHCP*** for left-hand circular polarization. The determination of the sense of the polarization is performed by observing the ratio of the right E-field over the left E-field.

The CP polarization is ***RHCP,*** if $\left|\frac{E_R}{E_L}\right| \succ 1$, or

LHCP, if $\left|\frac{E_R}{E_L}\right| \prec 1$

It is also useful to determine the axial ratio of the polarization of the AUT. The axial ratio is usually defined by the relation

$$R = \frac{|\mathrm{ER}|+|\mathrm{EL}|}{\left||\mathrm{ER}|-|\mathrm{EL}|\right|}$$

The axial ratio is often express in decibels by the relation

$$R_{dB} = 20 Log_{10} R$$

5. Matlab Program for Gain Calculation – *gain3ant*

The gain calculation algorithm described in Section 4 above has been implemented in Matlab. The program comprises a main routine *gain3ant* and four subroutines: *gain3acalc, getparam, freqchk* and *wi_read.* The latter is an existing utility specially programmed in-house to read the Wiltron VNA tabular (*.dat) data files. The routine *gain3acalc* is the gain calculation function, which implements the three-antenna gain algorithm. A local function to *gain3ant, getparam,* reads the Input Parameter file. A utility function, *freqchk,* compares the frequency values of the measurements to insure that the frequency of each data point matches. Finally, an additional utility, *ascanf,* was also created to read back into the Matlab workspace the gain array output file generated by *gain3ant.*

The gain3ant program is a MATLAB function, which returns to the MATLAB workspace, the multi-column gain array at termination.

The program is called with the following sequence:

```
GainArray = gain3ant;   or
            gain3ant;
```

where `GainArray` is an output array that will received at program termination the output array of gains calculated. The " ; " is also very important in the command line. Without it, the gain values will spill into the MATLAB workspace and will overwhelm the workspace window. If the output array is not required the second form is sufficient.

The *gain3ant* program assumes that two of the antennas are LP horns or antennas and that the third one, the test antenna or AUT, is either LP or CP. For usage, the antennas are labeled as such:

Antennas	Designation
Probe 1	A
Probe 2	B
AUT	C

The first column nomenclature is used to identify the antennas in communicating with the user. The letters A, B and C of the second column are used to identify the 3 antennas in the algorithm description and in the computer variable naming convention.

At the start of the program, a help window (see Figure 3) is opened explaining to the users the antenna nomenclature and gives a listing of all data, and input and output file requirements. The information to be provided by the user is as follows:

- The AUT polarization;
- The Input Parameter filename;
- The filenames for the correction measurements, i.e. the Cable-thru and the Attenuator calibrated frequency response files;
- The filenames for the linear, or horizontal and vertical polarization measurements; and,
- The filename for the output gain array.

The user must specify the polarization of the AUT, which is either linear or circular. When the AUT is linear, one set of three-antenna measurement pairs is required to calculate the LP AUT gain, and three measurement filenames must be provided via an Open File window selection. When the AUT is circular, two sets of three-antenna measurement pairs are required to calculate the AUT CP co-pol and cross-pol gains, i.e. 1 set for measurement with LP horns polarized horizontal and a second set for the LP horns polarized vertical.

The Input Parameter file contains experimental parameters (mostly non-changing) required for processing. They comprise a subtitle, the date of experiment, the three antenna names and the three antenna-pair separation distances. Two of the parameters, the subtitle and the date of the experiment, will permit identification of the specific measurement data set. Obviously, several measurement sessions will be conducted with these antennas, such as measuring with different circuit parameters, different frequency range, or may be using different horns. The subtitle, which will be used to tag each output graph, and the date of experiment will change normally for each Input Parameter file.

Each parameter line in the file is formatted as below:

```
Parameter Type    :   Parameter Value
```

where the " : " acts as a delimiter.

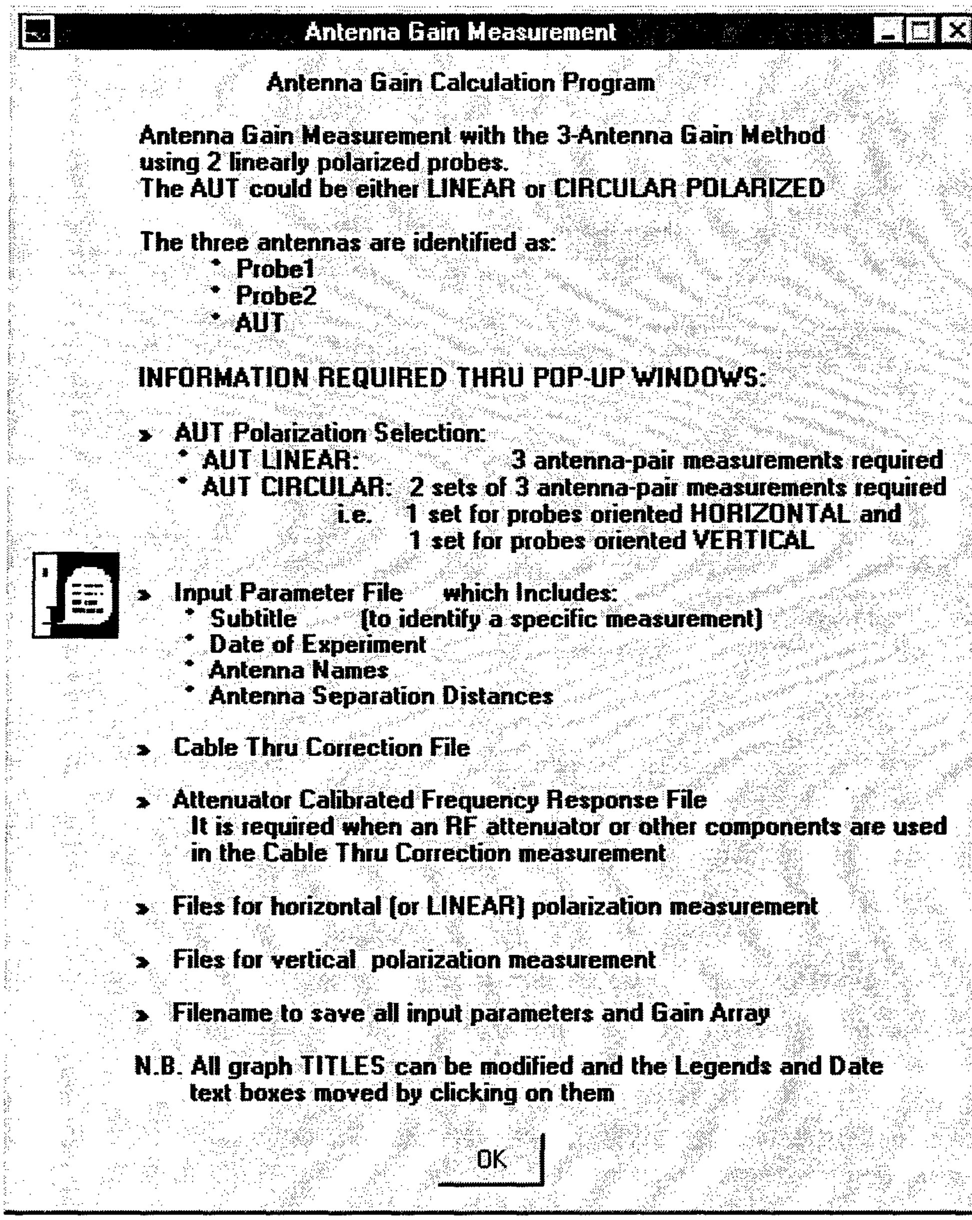

Figure 3. Opening Help Window

There are 8 input parameter types, and the template input parameter file is described next:

`SubTitle`	:	(for the graphs)
`Date`	:	(date of experiment)
`Probe1 Name`	:	
`Probe2 Name`	:	
`AUT Name`	:	
`Probe1-Probe2 Distance`	:	(in meters)
`Probe1-AUT Distance`	:	
`Probe2-AUT Distance`	:	

The listing order and the spelling of the various input parameter types as described above are very important but their cases and the white space are unimportant.

In Figure 4, a representation of the input requirements of the *gain3ant* program and of the output products it generates, is given. In the top half of the graph, the **Input Area**, the boxes represent the user selection, input data files to identify and other user input required by the program. In the bottom half, the **Output Area**, the boxes represent the various graphics generated and the gain data array computed and saved to disk. For each area, the boxes on the left side concern the gain measurement of a linear AUT or the horizontal partial gain measurements of a circularly polarized AUT. The boxes on the right side, conversely, are for the vertical partial gain measurements of a circular AUT. The boxes in the center Output Area represent the graphs generated for the CP AUT co-pol and cross-pol gain computations. In the lower **Post Processing section**, a program, *ascanf,* may be used to read back to the Matlab workspace the gain data array generated by *gain3ant* for further processing, computation or to produce more graphic output. Not shown in Figure 4 is the fact that the *gain3ant* function displays also into the MATLAB workspace the input parameters and other program parameters such as all the filenames and the respective VNA data identification strings. These permit the monitoring of all information entered into the program during its execution. Listings of the Matlab functions can be found in Appendix A.

When the program starts, the following input data are requested from the user:

1. Polarization selection of the AUT;
2. The Input Parameter file;
3. The Cable-thru correction file; and,
4. The calibrated Attenuator frequency response file;

During program execution, the gain calculation subroutine *gain3acalc* is called once for an LP AUT measurement, and twice for a circular AUT, i.e. once for each measurement set, where the LP antennas are horizontally and vertically polarized. The *gain3acalc* subroutine requires three measurement files (the three antenna-pair measurements) for processing and produces 2 graphs, which are listed below:

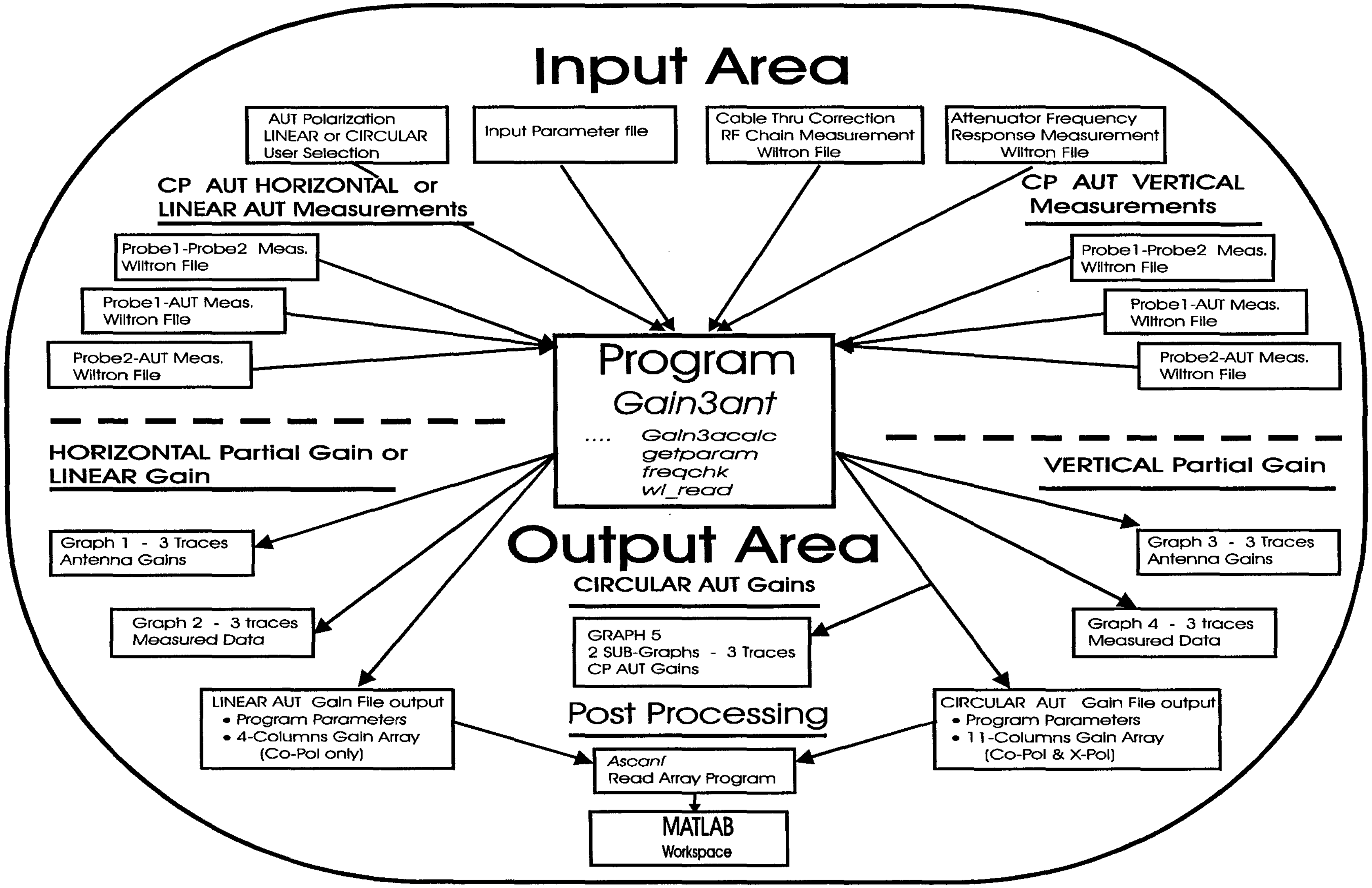

Figure 4. *gain3ant* **Program Usage Showing Input requirements and Output Generation**

1. A plot of all 3 gains, with the antenna names used as a legend;
2. A plot of the measurement data, which contains the three antenna-pair measurements traces, with the antenna-pair filename (without the extension) used as legend.

So for an LP AUT, 3 files are required and 2 graphs are produced. Only the LP co-pol gain is computed in the LP AUT case. After the gain calculation, a 4-column array is assembled and formatted as follow:

`[Frequency, GainA, GainB, GainC]` (All gains in dB)

and is saved to disk with user intervention, i.e. the user decides if the array is to be saved to disk, and in the affirmative, he selects a name for the file.

For a CP AUT, 6 files are required and 4 intermediary graphs are produced, i.e. 2 graphs for the horizontal partial gains and 2 more for the vertical.

In the circular AUT case, more processing is required after partial gain calculation with *gain3acalc*. The total gain is obtained from these preliminary gain calculations and is converted to obtain the AUT CP co-pol and cross-pol gains. As a result from these various calculations, a final 5th graph is generated. This is a double graph that displays the required CP AUT gains and indicates, in the title areas, the polarization sense. The top graph shows the CP co-pol and cross-pol gains of the AUT and the lower graph displays the relative cross-pol gain. An example of this double graph is shown later in Figure 9.

It could be mentioned at this point that the Date of Experiment is put on each graph at the origin of the axes. Because some user interaction with the graphs have been implemented, it is possible, after program termination, to relocate the graph legends and the date text box to a more adequate position on the graph with the mouse. Furthermore, the title block of each graph with its two components, the title and subtitle, can also be edited by clicking on them.

Finally, an 11-column array is assembled and formatted as follow:

`[Frequency, HGainA, HGainB, HgainC, VGainA, VGainB, VgainC,`
`Axial-Ratio, Rel-Cross-Pol, Co-Pol, Cross-Pol]` (All gains in dB)

and is written to disk with user intervention.

Header information always precedes the gain data array in the output file. It comprises the following information:

1. The Input Parameters;
2. The AUT polarization and the polarization sense (in the case of circular polarization);
3. All the measurement filenames with their four VNA identification strings; and,
4. The data column titles. The last line of the file header area starts with the '**' string followed with the name of each data column.

The output file can be read back subsequently into the Matlab workspace for further processing or more graphics manipulation. The m-file function *ascanf* has been specifically programmed for this purpose. Its usual calling sequence is shown below (do not forget the " ; "):

```
GainArray = ascanf('**',1);
```

The program starts, brings on the desktop an **Open File** window and the user selects the (*.txt) gain data file. The file is read, the header is printed into the Matlab workspace window and th``e gain data array is stored into the variable `GainArray`.

6. Measurement of gain of the AUT

One cavity-backed spiral antenna (referred to as the AUT in this report) was supplied for gain measurement. This antenna is circularly polarized and has a frequency range of 2-18 GHz. Nothing more was known about the AUT. The characteristics required were the main beam or boresight gain and the sense of polarization. As it was decided to measure the absolute gain by the three-antenna method, two TECOM horns were selected for the gain measurement.

These two horns are TECOM type 201187 (S/N 029 and 030) Dual Polarized Quad-Ridged horn assemblies. Their nominal frequency of operation is 4-18 GHz, the gain is 8-14 dBi and the average V.S.W.R. is 2.0:1. Although the TECOM horns are dual polarized, for performance purposes, only one connection was used for the measurements, as one of the connectors of the 030 horn was slightly damaged. Consequently, the horns were used as single polarized horns. The connectors labeled "HOR" were selected for the measurements. To implement the horizontal and vertical partial gain measurements, the positioners holding the antennas were rotated by 90° between measurements.

The antenna nomenclature for the three-antenna method measurement was implemented as described in Section 5, and the actual designation of the antennas is listed in the table below.

Antennas Names	Designation
TECOM 029	Probe 1
TECOM 030	Probe 2
AEL C-B Spiral	AUT

The separation distances between the antenna pairs are listed below:

Antenna Pairs	Distance in meters
Probe1-Probe2	3.806
Probe1-AUT	3.906
Probe2-AUT	3.906

As already mentioned earlier in paragraph 5, the antenna names and antenna-pair separation distances, along with the subtitle and the date of experiment are stored in the Input Parameter file.

Before gain measurements were made, the system was tested. The RF chains between the antennas and the VNA input ports (including power amplifiers, low noise amplifier (LNA), cables, attenuators, etc) were measured and adjusted for linear operation at the measurement frequency range. An experiment was also done to determine the amount of leakage in the system. The leakage between the transmission path, excluding the antenna, and the receiving path, including the probe antenna was measured. The leakage measurement was implemented with the following steps:

1. Terminate the transmitting cable (at the antenna), no signal is intentionally radiated within the chamber;
2. Leave the receiving (probe) antenna connected, this antenna will pick-up any leakage coming from the transmitting chain;
3. Do a frequency sweep, measure S21.

Figure 5 displays the leakage level as measured from the VNA. Signal levels varied from –90 to –85 dB with increasing frequency. This constitutes a very low level of leakage and noise, when it is compared to the antenna measurement levels, which vary between –15 to –40 dB for all the various measurements performed, and compared also to the *Cable-thru* measurements as seen in Figure 6.

The *return loss* of each antenna was also measured to ensure correct operation. The TECOM horn *S11* levels varied from –10 to –20 dB with an average of –15 dB for the frequency range used, whereas the AUT *S11* levels varied from –11 to –25 dB with an average of –20 dB.

The correction signals (described in Section 4) were then measured. The first signal, the *Cable-Thru* correction measurement, is the measurement of the complete RF circuit between the VNA ports but without the antennas. The feed-lines were disconnected from their respective antennas and were reconnected together to close the RF chain. It was also necessary to insert a 50 dB attenuator before the LNA for signal level adjustment and linear operation of the LNA. Figure 6 shows the *Cable-Thru* correction signal as measured with the VNA. The next correction signal to be measured was the *Atten* measurement, the calibrated frequency response measurement of the attenuator inserted in the first correction measurement. As explained in Section 4, this measurement is necessary to eliminate the effect of the insertion of the attenuator in the correction measurement circuit.

The attenuator, inserted in the circuit loop without the antennas, is a HP 8495D manual step attenuator. The following characteristics have been extracted from the product specifications:

- Frequency Range: 0 to 70 dB in 10 dB steps;
- Attenuation accuracy: between ±0.3 to 1.7 dB increasing with attenuation level and with frequency;
- Attenuation repeatability: 0.01 dB, dc to 18 GHz.

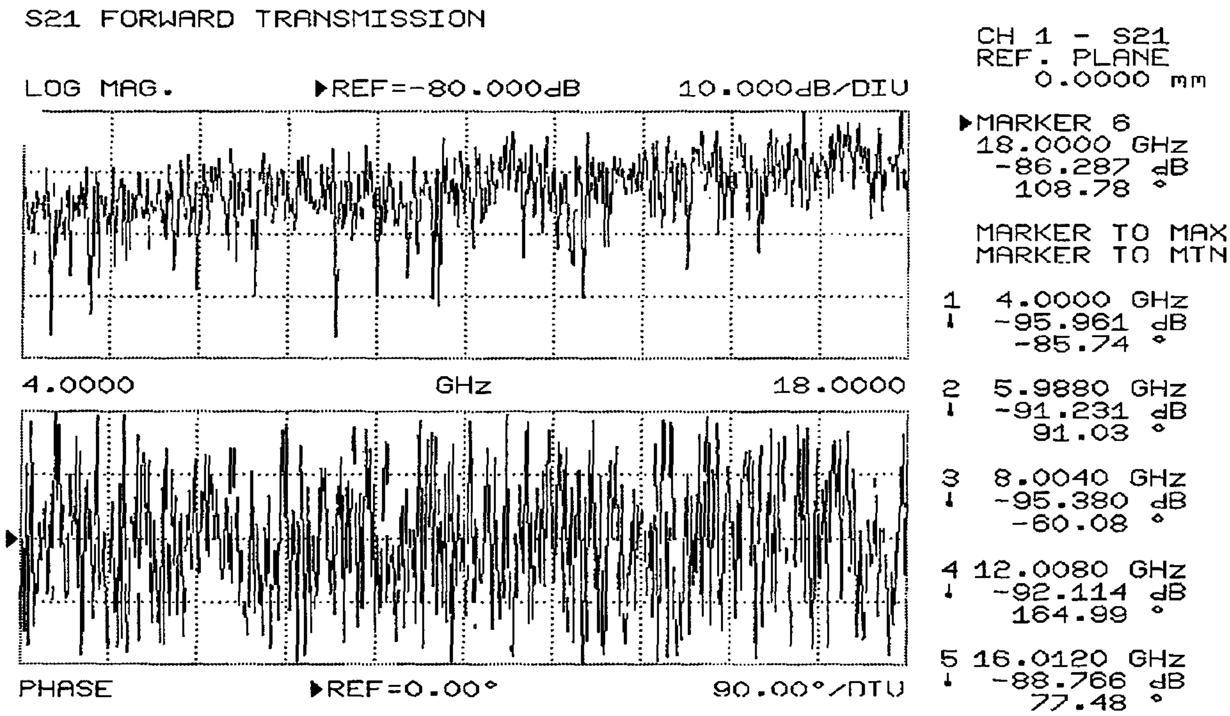

Figure 5. **Measurement of Leakage with Transmit Chain Terminated at the AUT.**

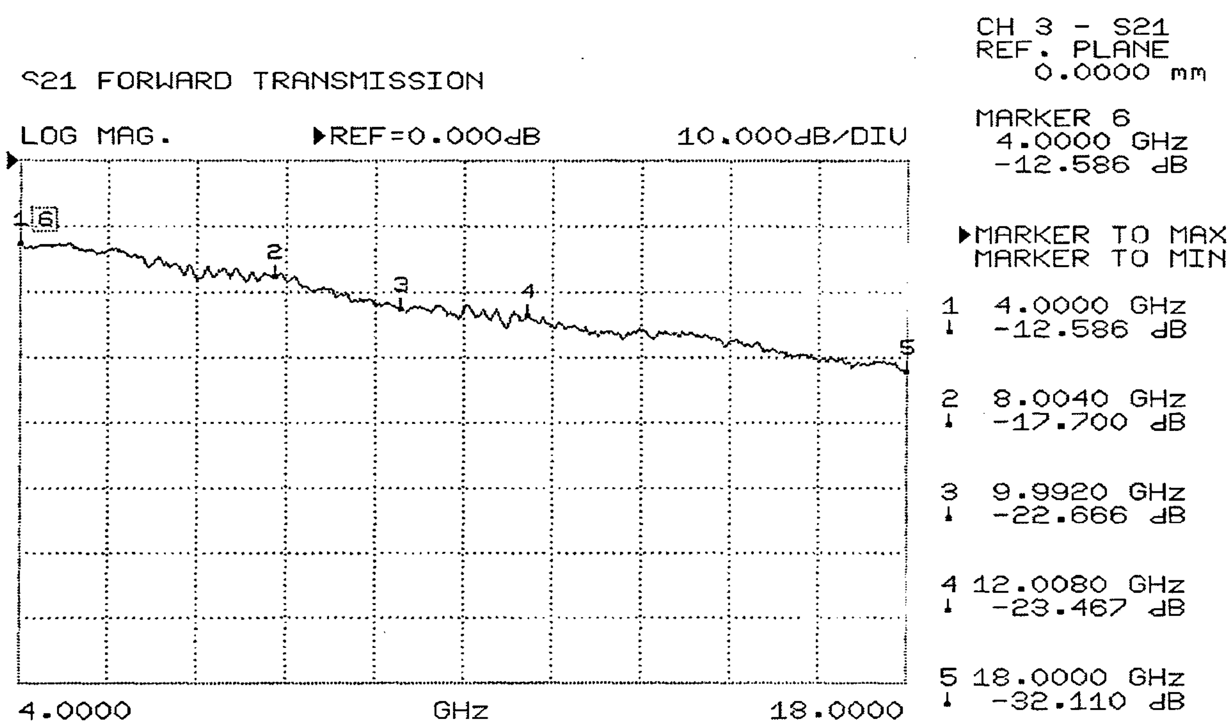

Figure 6. **Measurement of Cable-Thru Circuitry with 50 dB Attenuation Added at the LNA.**

With such characteristics it was deemed necessary to perform a calibrated measurement of the attenuator at each attenuation step to insure a very precise gain evaluation. The measurement was performed for the same frequency points as the gain measurement. As a result of its good attenuation repeatability the attenuator was measured only once and then the data filed to disk. These calibrated attenuation measurements will be used, as required, for all the gain measurements at the same frequency. Figure 7 is a graph of the attenuation of all the 8 steps of the HP 8495D manual step attenuator.

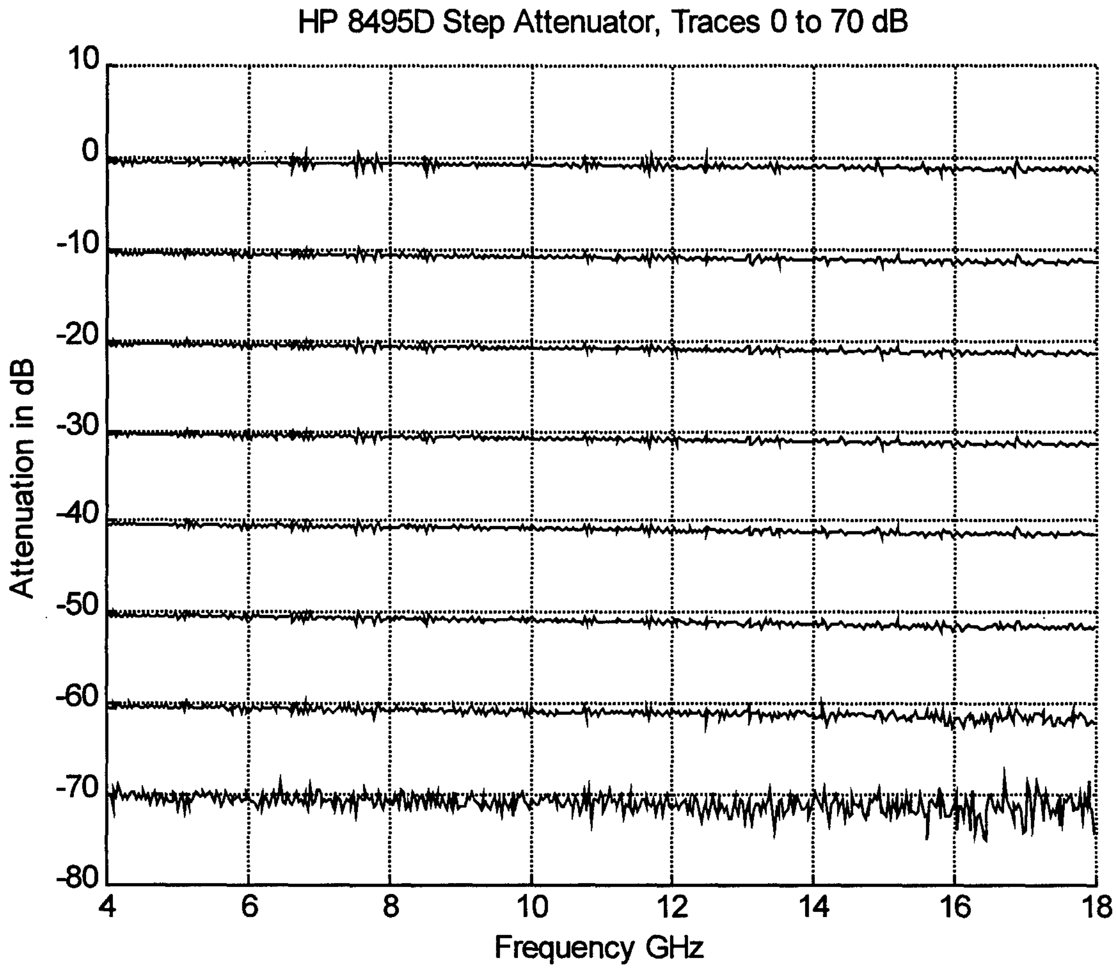

Figure 7. Attenuation of HP 8495D Step Attenuator, All Steps

In Figure 8, a list of the main experimental measurement setups and operation for the three-antenna gain measurement method is represented. Although, more preparatory and experimental work is required for the complete gain measurement exercise, the list addresses the important experimental steps for the method implementation.

For the CP gain measurement of the AUT, as explained in Sections 4 and 5 above, two sets of measurements were performed to get the horizontal and vertical partial gain components of the CP gain of the AUT. The calculation of the total gain, the CP co-pol and cross-pol gains of the AUT and the determination of the sense of the CP polarization followed

Experimental Procedures for the Three-Antenna Gain Measurement Method

- Measure return loss (S11) of all antennas.
- Perform a correction measurement of the RF chain with the antennas removed and the attenuator(s) and/or cable added to close the circuit (*Cable-Thru*). Save the measurement data to disk;
- Perform a calibrated measurement (*S21*) of the attenuator(s) and/or cable added to the circuit (*Atten*). Save the measurement data to disk;
- Measure the 3 antenna-pair separation distances in meters; the distances, along with the date of experiment, a subtitle and the antenna names are written to the Input parameter file;
- Measure the antenna-pairs in the suggested following order:

  Probe 1 – Probe 2

  Probe 1 –AUT

  Probe 2 - AUT

1. For Linearly polarized AUT

   Measure 1 set of 3 antenna-pairs with three antennas similarly polarized. Save the 3 measurement data to disk.

2. For Circularly polarized AUT

   Measure 2 sets of 3 antenna-pairs to perform horizontal and vertical partial gain measurements.

   1) Measure with Probe 1 and Probe 2 horizontally polarized. Save the 3 measurement data to disk;
   2) Measure with Probe 1 and Probe 2 vertically polarized. Save the 3 measurement data to disk.

Figure 8. Experimental Setups and procedures for the Three-Antenna Gain Measurement Method

with the use of the Matlab program *gain3ant*. The program produced 5 graphs showing measured data, partial gains and CP gains. The first 4 graphs present only intermediary results, but the last and most important graph, shown below in Figure 9, is a double plot graph which presents the complete results including the required CP gains and the polarization sense information. It displays, on the top plot, two traces, the CP co-pol and cross-pol gains of the AUT, and on the lower plot, the CP relative cross-pol gain. The sense of the circular polarization is indicated in the graph titles. The polarization sense is LHCP, and the gain varies between 2.2 and 5.8 dB for the frequency range of 4-18 GHz. The subtitle establishes some particularity of the measurement and the date of experiment is written on the graph. The form of this graph is as generated by Matlab graphic using partially automatic scaling.

However, because Matlab is very interactive and easy to use, the graphs can be managed further by a user familiar with the language and re-scaled for an improved display. Moreover, the resulting gain data are stored in array format into a disk file and easily accessible. Figure 10 displays an example of the contents of the Matlab workspace as generated by the program during its execution. It is accompanied by an example also of the file header of the gain array output file. This information connects the resulting gain data on the graphs with the source measurement files.

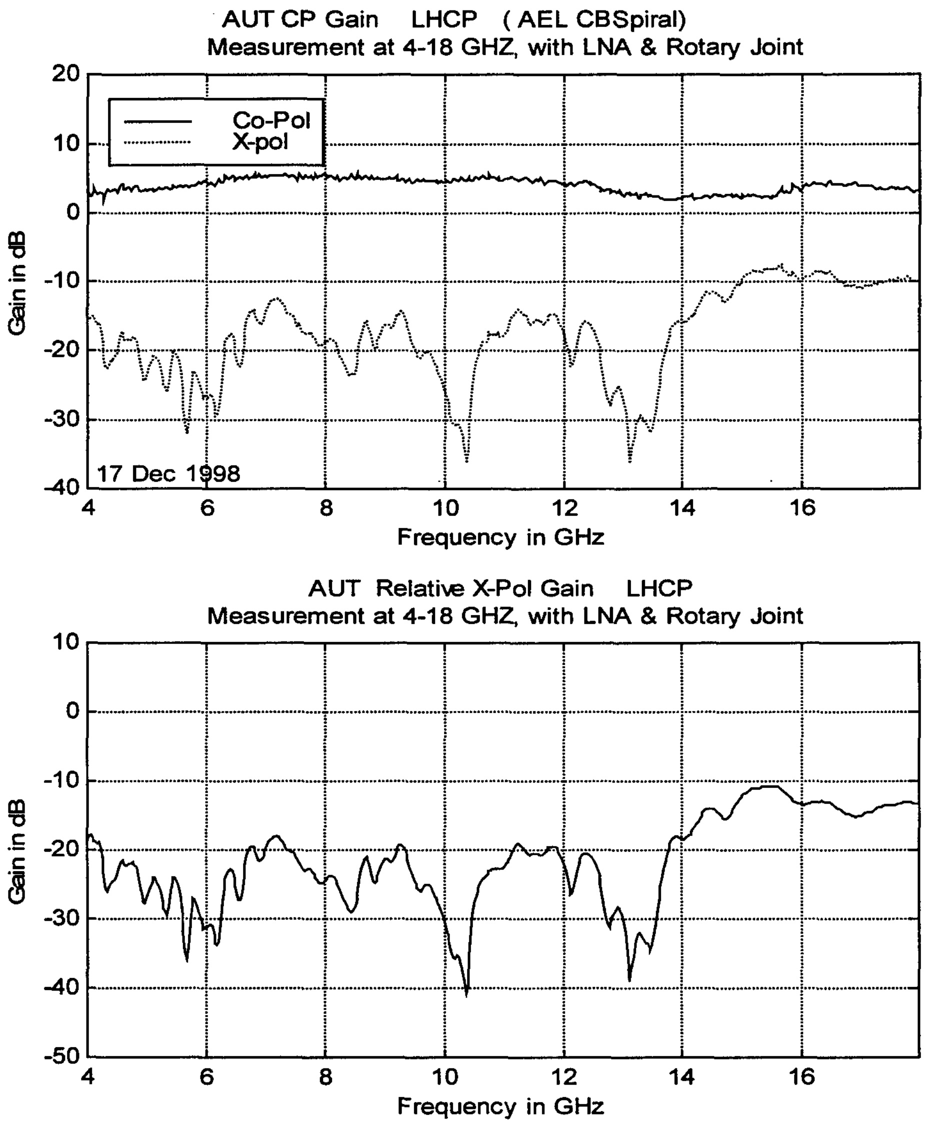

Figure 9. Circularly Polarized AUT Gain

Matlab Workspace Program Output Example

```
» Gainarray=gain3ant;
Input Parameter Filename:              D:\CLAUDE\matlab\data\CFEWC1217\inputparam.txt
SubTitle:                              Measurement at 4-18 GHZ, with LNA & Rotary Joint
Date:                                  17 Dec 1998
Probe1 Name:                           TECOM029
Probe2 Name:                           TECOM030
AUT Name:                              AEL CBSpiral
Probe1-Probe2 Distance:                3.806 m
Probe1-AUT Distance:                   3.906 m
Probe2-AUT Distance:                   3.906 m
Cable Thru Correction Filename:        D:\CLAUDE\matlab\data\CFEWC1217\S21thru5.dat
VNA Identification:                    S21THRUCABLE 97DEC17.0739 ROT.JOINT.IN MK
Attenuator Frequency Response Filename: D:\CLAUDE\matlab\data\CFEWC1217\HPaten50.dat
VNA Identification:                    HP.ATTEN50DB 97DEC02.1122 SRC.ATTEN0DB MK
HORIZONTAL, Probe1-Probe2 Filename:     D:\CLAUDE\matlab\data\CFEWC1217\H030029h.dat
HORIZONTAL, Probe1-AUT Filename:        D:\CLAUDE\matlab\data\CFEWC1217\H029aut.dat
HORIZONTAL, Probe2-AUT Filename:        D:\CLAUDE\matlab\data\CFEWC1217\H030AUT.dat
VNA Identification:                    H030029H     97DEC17.0826 ROT.JOINT.IN MK
VNA Identification:                    H029AUT      97DEC17.0800 ROT.JOINT.IN MK
VNA Identification:                    H030AUT      97DEC17.0816 ROT.JOINT.IN MK
Max AUT Gain (H):                      3.5736 dB at 7.332GHz.
VERTICAL, Probe1-Probe2 Filename:      D:\CLAUDE\matlab\data\CFEWC1217\v030029v.DAT
VERTICAL, Probe1-AUT Filename:         D:\CLAUDE\matlab\data\CFEWC1217\V029AUT.dat
VERTICAL, Probe2-AUT Filename:         D:\CLAUDE\matlab\data\CFEWC1217\V030AUT.dat
VNA Identification:                    V030029V     97DEC17.0834 ROT.JOINT.IN MK
VNA Identification:                    V029AUT      97DEC17.0804 ROT.JOINT.IN MK
VNA Identification:                    V030AUT      97DEC17.0812 ROT.JOINT.IN MK
Max AUT Gain (V):                      3.0769 dB at 8.76GHz.
AUT Polarization:                      CIRCULAR LHCP
Output Array Filename:                 D:\CLAUDE\matlab\data\CFEWC1217\testcircular.txt
»
```

Data File Header Example

```
Antenna Gain Measurement:             3-Antenna Method
SubTitle:                              Measurement at 4-18 GHZ, with LNA & Rotary Joint
Date:                                  17 Dec 1998
Probe1 Name:                           TECOM029
Probe2 Name:                           TECOM030
AUT Name:                              AEL CBSpiral
AUT Polarization:                     CIRCULAR  LHCP
Probe1-Probe2 Filename (Hor Pol):     D:\CLAUDE\matlab\data\CFEWC1217\H030029h.dat
VNA Identification:                   H030029H     97DEC17.0826 ROT.JOINT.IN MK
Probe1-AUT Filename (Hor Pol):        D:\CLAUDE\matlab\data\CFEWC1217\H029aut.dat
VNA Identification:                   H029AUT      97DEC17.0800 ROT.JOINT.IN MK
Probe2-AUT Filename (Hor Pol):        D:\CLAUDE\matlab\data\CFEWC1217\H030AUT.dat
VNA Identification:                   H030AUT      97DEC17.0816 ROT.JOINT.IN MK
Probe1-Probe2 Filename (Ver Pol):     D:\CLAUDE\matlab\data\CFEWC1217\v030029v.DAT
VNA Identification:                   V030029V     97DEC17.0834 ROT.JOINT.IN MK
Probe1-AUT Filename (Ver Pol):        D:\CLAUDE\matlab\data\CFEWC1217\V029AUT.dat
VNA Identification:                   V029AUT      97DEC17.0804 ROT.JOINT.IN MK
Probe2-AUT Filename (Ver Pol):        D:\CLAUDE\matlab\data\CFEWC1217\V030AUT.dat
VNA Identification:                   V030AUT      97DEC17.0812 ROT.JOINT.IN MK
Cable Thru Correction Filename:       D:\CLAUDE\matlab\data\CFEWC1217\S21thru5.dat
VNA Identification:                   S21THRUCABLE 97DEC17.0739 ROT.JOINT.IN MK
Attenuator Frequency Response Filename: D:\CLAUDE\matlab\data\CFEWC1217\HPaten50.dat
VNA Identification:                   HP.ATTEN50DB 97DEC02.1122 SRC.ATTEN0DB MK
Input Parameter Filename:            D:\CLAUDE\matlab\data\CFEWC1217\inputparam.txt
Probe1-Probe2 Distance:              3.806 m
Probe1-AUT Distance:                 3.906 m
Probe2-AUT Distance:                 3.906 m
** FREQ    HGainP1   HGainP2  HGainAUT    VGainP1    VGainP2  VGainAUT  AxRatio    RelX-Pol  C-
PGain   X-PGain   All in dB
```

Figure 10. Matlab Workspace Program Output and Data File Header Examples

7. Conclusion

The on-axis gain of a cavity-backed spiral circularly polarized antenna has been measured using the three-antenna method of gain measurement. The CP co-pol gain of the AUT varied between 2.2 and 5.8 dB in the frequency range of 4-18 GHz, and the polarization sense is LHCP. The production of this report had a double purpose. The first one was to report on the gain measurement of an antenna using absolute gain measurement techniques and presenting the resulting gains and polarization information. As mentioned above, the gains were calculated using several antenna main beam (on-axis) measurements where three antennas taken 2-by-2 were measured. The second and foremost purpose was to present the three-antenna method for measuring the absolute gain of an antenna. The mathematical algorithm was presented in detail and its implementation into a Matlab program was also described.

References

1. Antenna Measurement Techniques, Gary E. Evans, Artech House, 1990, Chapter 3.3.

2. "Microwave Antenna Measurements", Scientific-Atlanta Inc., Atlanta, Georgia, USA, July 1970, Chapter 8.

3. Near-Field Antenna Measurements, Dan Slater, Artech House, 1991, Chapter 2.

4. Claude J. Brochu and Gilbert A. Morin, "Data Acquisition Software for DREO's Near-Field Antenna Measurement Facility", DREO Report No 1253, December 1994.

5. Claude J. Brochu, John W. Moffat, and Gilbert A. Morin, "Optical Alignment Of The Spherical Antenna Measurement System", DREO Report No 1316, November 1997.

Appendix A - Matlab Program *"gain3ant"* Listings

This appendix produces the listing of the Matlab program *gain3ant* that computes the gain of an antenna using the three-antenna method.

The following Matlab program (m-files) are listed:

gain3ant	main gain computation function.
getparam	local function to *gain3ant* to read the input parameters
gain3acalc	subroutine to implement the three-antenna method formulas.
freqchk	subroutine to check that all data have the same frequency points.
wi_read	subroutine to read the Wiltron VNA tabular data measurement files.
ascanf	separate function to read back to the Matlab workspace the gain array computed by *gain3ant* and saved to a disk file.

gain3ant

```
function GainARRAY=gain3ant
%
%  This program calculates the GAIN of an Antenna (AUT) using the
%  3-antennas algorithm.
%
%  It is assumed that two of the antennas are  LP horns (linearly polarized)
%  and that the AUT is either LP or CP i.e. (linearly or circularly polarized).
%
%  The antennas are labelled as such:
%
%         Probe1   <->   A
%         Probe2   <->   B
%         AUT      <->   C
%
%  The first column nomenclature is used to identify the antennas
%  in communicating with the user.
%  The letters A, B and C of the second column are used to identify
%  the 3 antennas in the program listing.
%  So variable names terminated with 1, 2 or 3 of these letters refer
%  to the respective antenna(s)
%
%  -------------------------------------------------------
%  Polarization selection
%  At the beginning, the user selects the polarization of the AUT
%  The AUT is either LINEAR (LP) or CIRCULAR (CP) polarized.
%   For LP AUT measurements,  only  the Co-Pol gain is calculated
%   For CP AUT measurements, the Co-Pol, X-Pol and rel X-Pol gains are
%  calculated.
%
%  -------------------------------------------------------
%  Data Input common to both type of AUT polarization
%
%  The program reads 3 files at the start to get input parameters and
%  correction data
%
%  1. The Input Parameter file,
%  2. The Cable Thru Correction file, and
%  3. The Attenuator calibrated Frequency Response file
%
%  -------------------------------------------------------
%  Input Parameter file Characteristics
%
%   The Input Parameter file includes:
%
%  Subtitle, Date of experiment,
%  Probe1, Probe2 and AUT names,
%  Probe1-Probe2, Probe1-AUT and Probe2-AUT separation distances
%
%  Each parameter line in the Input Parameter file is formatted as follows:
%
%  Parameter Type :  Parameter Value   (where the ":" acts as a delimiter)
%
%  The 8 expected parameter types (without the single quote) are:
%
%  'SubTitle'                                 -->   to add to titles in graphs
%  'Date'                                     -->   date of experiment
%  'Probe1 Name', 'Probe2 Name', 'AUT Name'   -->   antenna names
%  'Probe1-Probe2 Distance'                   -->   antenna separation distances
%  'Probe1-AUT Distance'
%  'Probe2-AUT Distance'
```

```
%
% N.B.  the correct spelling of the various types as described above
%       is very important, but not their cases
%
% -------------------------------------------------------
% Calibration Measurement
%
% The Cable Thru Correction is the measurement of the RF circuitry less the
% antennas,  it is done to establish the correction to apply to the
% 3-antenna method formula.
%
% The RF circuitry includes cables, RF amps, LNA and possibly attenuators.
% When measuring Cable Thru (i.e. the total RF chain less the antennas)
% it may be necessary to add attenuators to adjust levels for  the VNA
% and/or LNA input.  So, the attenuator calibrated frequency response must be
% substracted for the correction calculation.
%
% -------------------------------------------------------
% LP AUT measurements  (only Co-Pol gain calculated)
%
% 1. One set of 3 antenna-pair measurements is required to calculate
%    the  LP AUT Co-Pol Gain.
%
% 2. For the LINEAR AUT measurement set:
%       1 Graph displays the 3 antenna gains and
%       1 Graph displays the 3 measured data traces
%
% 3. The output array "GainARRAY" is assembled and filed (output file)
%    with the following format:
%                 [ FREQ GainA GainB GainC ],  or a 4-column array.
%
% -------------------------------------------------------
% CP AUT measurements (Co-Pol, X-Pol and rel X-Pol gains calculated)
%
% 1. sets of 3 antenna-pair measurements are required:
%     i.e. 1 set for probes with their E-field oriented HORIZONTAL and
%          1 set for probes with their E-field oriented VERTICAL'.
%
% 2. The CP TOTAL GAIN of the AUT is calculated.
%
% 3. The Relative X-Pol gain is calculated using the Magnitude and Phase
%    of the Horizontal and Vertical measurement of one of the antenna pair,
%    (the AC pair).
%
% 4. These results are used to compute the CP AUT Co-Pol and X-Pol gains.
%
% 5. The Axial Ratio of the AUT is also calculated.
%
% 6. The linear and dB representation of all these terms are calculated.
%
% 7. For each polarized measurement set:
%       1 Graph displays the 3 antenna gains and
%       1 Graph displays the 3 measured data traces.
%
% 8. 1 double graph display is generated:
%       the top graph displays the Co-Pol and X-Pol gain of the CP AUT,
%       the lower garph displays the Relative X-Pol gain.
%
% 9. The output array "GainARRAY" is assembled and filed (output file)
%    with the following format:
%
%   [ FREQ  HGainA  HGainB  HGainC  VGainA  VGainB  VGainC Axial Ratio ...
%   Rel X-Pol  Co-Pol gain  X-Pol gain ],  or an 11-column array.
```

```
%
% ----------------------------------------------------------
% N.B.
% The output file contains also header information which comprises:
% Input parameters, measurement filenames and VNA Wiltron identifier strings.
% The last line of the header area in the file starts with the '**' string
% followed with the name of each data column of the "GainARRAY".
%
% For further data processing, this file can be read with the m-file 'ascanf'
% as shown below:
%
%                     [array, count] = ascanf('**',1)
%
% ----------------------------------------------------------
% SUBROUTINES Called:
%    getparam  (LOCAL)          read 1 line of Input Parameter file
%    wi_read                    read Wiltron tabular data file(*.dat)
%    gain3acalc                 3-antenna method calculator
%    freqchk                    compare frequency values between data files
%
% ----------------------------------------------------------
% Main Variables:
% Convention:
% -  Variable names terminated with 1, 2 or 3 of the A,B or C letters refer
%    to the respective antenna(s)
% -  Variables names starting with | L | H | V |
%                     denotes LINEAR, HORIZONTAL or VERTICAL polarisation
% -  Variables ending with 'dB' denote computed data arrays in dB format
%    i.e. (20*log10(data) or 10*log10(data) whatever the case may be
%
% FREQ, Freq              Frequency vectors
% DistABACBC              Separation distances for the 3 antenna-pairs
% SUBTITLE                Graph subtitle to identify a specific measurement
% EXPDATE                 Date of experiment
% nnFname, nnPath         filename and path (nn=|Param|Thru|Atten|AB|AC|BC|)
% xxName                  Antenna name (xx=|Probe1|Probe2|AUT|)
% NAMESABC                Array of names for the 3 antennas
% ThruCor                 Measured data for Cable Thru Correction
% AttenCal                Measured data for Attenuator calibrated frequency response
% AB, AC, BC              Measured data for the 3 antenna-pairs
% pGainABC                polarisation 'p', Array of gains for the
%                         3 antennas, (p=|L|H|V|)
% pFnameABACBC            polarisation 'p', Array of filenames for the
%                         3 antenna-pairs, (p=|L|H|V|)
% nnIdent                 VNA Identification string array, (nn=|Thru|Atten|)
% pIdentaa                VNA Identification string array,
%                            (p=|L|H|V|, (aa=|AB|AC|BC)
% EhEv                    Array of electric field Eh and Ev, 2-column complex array
% ErEl                    Array of E field right and left polarization sense,
%                         2-column complex array
% ABSErEl                 Absolute value of complex array ErEl
% AxialRatio (dB)         Axial Ratio (linear and dB)
% CPrelXPgain (dB)        CP relative X-Pol gain  (linear and dB)
% CPCoPgain (dB)          CP Co-Pol gain  (linear and dB)
% CPXPgain (dB)           CP X-Pol gain  (linear and dB)
% ARrelXPGcPGxP           super gain array of the 4 gain vectors above (dB values)
%
% ----------------------------------------------------------
%
% Programmed by Claude Brochu                          Date:           Mar   1998
%                                                      Revision 1:   7 Apr   1998
%                                                      Revision 2:    Sep\Oct 1998
%
```

```
%  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

global FREQ DISTABACBC CORRECTION SUBTITLE EXPDATE NAMESABC

set(0,'DefaultAxesColorOrder',[0 0 0], ...
   'DefaultAxesLineStyleOrder','-|:|-.|--')

%  Starting Message

StartMsg={
   '                    Antenna Gain Calculation Program';'';
   'Antenna Gain Measurement with the 3-Antenna Gain Method';
   'using 2 linearly polarized probes.';
   'The AUT could be either LINEAR or CIRCULAR POLARIZED';'';
   'The three antennas are identified as:';
   '        °  Probe1'; '        °  Probe2';'         °  AUT';'';
   'INFORMATION REQUIRED THRU POP-UP WINDOWS: ';'';
   '»   AUT Polarization Selection:';
   '     °  AUT LINEAR:                  3 antenna-pair measurements required';
   '     °  AUT CIRCULAR:  2 sets of 3 antenna-pair measurements required';
   '                       i.e.    1 set for probes oriented HORIZONTAL and';
   '                               1 set for probes oriented VERTICAL';'';
   '»   Input Parameter File     which Includes:';
   '      °  Subtitle        (to identify a specific measurement)';
   '      °  Date of Experiment';
   '      °  Antenna Names';
   '      °  Antenna Separation Distances';'';
   '»   Cable Thru Correction File';'';
   '»   Attenuator Calibrated Frequency Response File';
   '       It is required when an RF attenuator or other components are used';
   '       in the Cable Thru Correction measurement';'';
   '»   Files for horizontal (or LINEAR) polarization measurement';'';
   '»   Files for vertical  polarization measurement';'';
   '»   Filename to save all input parameters and Gain Array';'';
   'N.B. All graph TITLES can be modified and the Legends and Date';
   '       text box moved by clicking on them'
};

h=helpdlg(StartMsg,'                              Antenna Gain Measurement');
waitfor(h)

%  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%  AUT Polarization Selection

titre ='"AUT Polarization" Selection';
msg   ='Specify the AUT polarization';
AUTPol=questdlg(msg,titre,'LINEAR','CIRCULAR','LINEAR');

%  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%  Get the Input Parameter filename which includes:
%  Subtitle, Date of experiment,
%  Probe1, Probe2, AUT names,
%  P1-P2, P1-AUT, P2-AUT separation distances

Title='"Input Parameter" File Selection';
[ParamFname ParamPath]=uigetfile('*.txt', Title);

if ParamFname==0    msg={'CANCEL Selected'; ''; 'ABORTING'};      %  CANCEL selected
   errordlg(msg,Title), return, end

disp(['Input Parameter Filename:          ' ParamPath ParamFname]);   cd (ParamPath);
```

```
[fid,message]=fopen([ParamPath ParamFname]);                    %      open Input
Parameter file
if fid == -1  msg={message;''; 'ABORTING'};
   errordlg(msg,'ERROR openning Input Parameter file'); return, end

% Read Input Parameters file

ParamList=char('SubTitle', 'Date', 'Probe1 Name', 'Probe2 Name', 'AUT Name', ...
    'Probe1-Probe2 Distance', 'Probe1-AUT Distance', 'Probe2-AUT Distance');

% If the parameter type:
%         °  is not found   or,
%         °  the format of the line is not as described above,  or
%         °  an EOF is encountered,
% the output variable errflg=1, and
% the parameter Value is empty

[SUBTITLE,   errflg]=getparam(fid,ParamList(1,:));  if errflg return, end
[EXPDATE,    errflg]=getparam(fid,ParamList(2,:));  if errflg return, end
[Probe1Name, errflg]=getparam(fid,ParamList(3,:));  if errflg return, end
[Probe2Name, errflg]=getparam(fid,ParamList(4,:));  if errflg return, end
[AUTName,    errflg]=getparam(fid,ParamList(5,:));  if errflg return, end
[P1_P2Dist,  errflg]=getparam(fid,ParamList(6,:));  if errflg return, end
[P1_AUTDist, errflg]=getparam(fid,ParamList(7,:));  if errflg return, end
[P2_AUTDist, errflg]=getparam(fid,ParamList(8,:));  if errflg return, end

fclose(fid);

DISTABACBC =str2num(char(P1_P2Dist, P1_AUTDist, P2_AUTDist));
NAMESABC   =char(Probe1Name, Probe2Name, AUTName);

% Echo to MATLAB Workspace

disp(['SubTitle:                              ' SUBTITLE])
disp(['Date:                                  ' EXPDATE])
disp(['Probe1 Name:                           ' Probe1Name])
disp(['Probe2 Name:                           ' Probe2Name])
disp(['AUT Name:                              ' AUTName])
disp(['Probe1-Probe2 Distance:                 ' num2str(DISTABACBC(1)) ' m'])
disp(['Probe1-AUT Distance:                    ' num2str(DISTABACBC(2)) ' m'])
disp(['Probe2-AUT Distance:                    ' num2str(DISTABACBC(3)) ' m'])

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Read Cable Thru Correction

errtitle='Error Reading File';
msg     ='"Cable thru Correction" File Selection';

[ThruFname ThruPath]=uigetfile('*.dat', msg);
if ThruFname==0   errmsg ={'File Selection Cancelled';'';'ABORTING'};
   errordlg(errmsg, '   File Selection');  return, end

disp(['Cable Thru Correction Filename:     ' ThruPath,ThruFname]); cd(ThruPath);

[FREQ, ThruCor, PHASE, ERR_INDEX, ThruIdent]=wi_read([ThruPath,ThruFname],'freq');
if ERR_INDEX ~= 0
   errmsg={['   ERROR   ' int2str(ERR_INDEX) ' reading file:  ']; ...
        [ThruPath,ThruFname]; '';'     ABORTING'};
   errordlg(errmsg, errtitle); return; end;

disp(sprintf('%s%s','VNA Identification:                ', ThruIdent'))
```

```
%  Read Attenuator Calibrated Frequency Response

msg='"Attenuator Calibrated Frequency Response" File Selection - CANCEL for NONE';

[AttenFname AttenPath]=uigetfile('*.dat', msg);
if AttenFname==0
   AttenCal=0;
else
   disp(['Attenuator Frequency Response Filename: ' AttenPath,AttenFname]);
   [Freq, AttenCal, PHASE, ERR_INDEX, AttenIdent]=wi_read([AttenPath,AttenFname],
'freq');
   if  ERR_INDEX ~= 0
      errmsg={['   ERROR  ' int2str(ERR_INDEX) ' reading file:  '];...
            [AttenPath,AttenFname];'';'    ABORTING'};
      errordlg(errmsg, errtitle); return; end;

   disp(sprintf('%s%s','VNA Identification:                ', AttenIdent'))
end;

%  All measurement data from the VNA must have the same frequency values
if freqchk(Freq) return, end                   %     Frequency values different

CORRECTION = ThruCor - AttenCal;               %     CORRECTION for cables, etc...

%  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%  Proceed with GAIN CALCULATION

%  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

switch AUTPol

case 'LINEAR'                                          %LINEAR Polarized AUT

   [LGainABC, LFnameABACBC, LIdentAB, LIdentAC, LIdentBC, errflg] = gain3acalc('L');
   if errflg return,end
   disp(['AUT Polarization:                  ' AUTPol]);

   % SAVING DATA TO FILE  - the freq and the 3 Gains into a 4-columns array

   GainARRAY = [FREQ,LGainABC];
   TitleRow  ='  FREQ     GainP1    GainP2    GainAUT   All in dB';

   [dfile,dpath] = uiputfile('*.txt','Save the LINEAR Gain Array to File');
   if ~((size(dpath,2) == 1) & (size(dfile,2) == 1));
      fid = fopen([dpath,dfile],'wt');
      disp(['Output Array Filename:            ' dpath,dfile]);

      %      Header information

      fprintf(fid,'%s\n',  'Antenna Gain Measurement:   3-Antenna Method');
      fprintf(fid,'%s\n', ['SubTitle:                  ' SUBTITLE]);
      fprintf(fid,'%s\n', ['Date:                      ' EXPDATE]);
      fprintf(fid,'%s\n', ['Probe1 Name:               ' Probe1Name]);
      fprintf(fid,'%s\n', ['Probe2 Name:               ' Probe2Name]);
      fprintf(fid,'%s\n', ['AUT Name:                  ' AUTName]);

      fprintf(fid,'%s\n', ['AUT Polarization is:       ' AUTPol]);

      fprintf(fid,'%s\n', ['Probe1-Probe2 Filename:    ' LFnameABACBC(1,:)]);
      fprintf(fid,'%s%s\n','VNA Identification:       ', LIdentAB');
      fprintf(fid,'%s\n', ['Probe1-AUT Filename:       ' LFnameABACBC(2,:)]);
```

```
      fprintf(fid,'%s%s\n','VNA Identification:        ', LIdentAC');
      fprintf(fid,'%s\n', ['Probe2-AUT Filename:        ' LFnameABACBC(3,:)]);
      fprintf(fid,'%s%s\n','VNA Identification:        ', LIdentBC');
      fprintf(fid,'%s\n', ['Cable Thru Correction Filename: ' ThruPath,ThruFname]);
      fprintf(fid,'%s%s\n','VNA Identification:        ', ThruIdent');

      if AttenPath~=0
      fprintf(fid,'%s\n', ['Attenuator Frequency Response Filename: ' AttenPath,
AttenFname]);
      fprintf(fid,'%s%s\n','VNA Identification:        ', AttenIdent');
      end

      fprintf(fid,'%s\n', ['Input Parameter Filename:    ' ParamPath ParamFname]);

    fprintf(fid,'%s\n', ['Probe1-Probe2 Distance:     ' num2str(DISTABACBC(1)) ' m']);
    fprintf(fid,'%s\n', ['Probe1-AUT Distance:        ' num2str(DISTABACBC(2)) ' m']);
    fprintf(fid,'%s\n', ['Probe2-AUT Distance:        ' num2str(DISTABACBC(3)) ' m']);

      fprintf(fid,'%s\n', ['**' TitleRow]);

      %  Data
      fprintf(fid,'%9.4f %9.4f %9.4f %9.4f\n',GainARRAY');
      fclose(fid);
   end;

   %   %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

case 'CIRCULAR'                                       %CIRCULAR Polarized AUT

   %   Partial Gain Calculation
   %   Horizontal Partial Gain (obtained with probe polarization oriented horizontal)

   [HGainABC, HFnameABACBC, HIdentAB, HIdentAC, HIdentBC, errflg] = gain3acalc('H');

   if errflg return, end

   %   Vertical Partial Gain (obtained with probe polarization oriented vertical)

   [VGainABC, VFnameABACBC, VIdentAB, VIdentAC, VIdentBC, errflg] = gain3acalc('V');

   if errflg return, end

   %   AUT Partial gains for H and V polarization are added  to calculate
   %   the AUT Total Gain in dB

   TotalGain=10*log10( (10.^(HGainABC(:,3)/10)) + (10.^(VGainABC(:,3)/10)));

   %   %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

   %   Calculation of the AUT Circular Co-Pol and X-Pol gains (antenna C)

   %   For this calculation, the H and V data for the AC-pair are reread
   %   to get the amplitude and phase data required to calculate
   %   the Relative CP X-Pol gain of the AUT.  This last parameter will be used
   %   to correct the Total Gain calculated above, and from there, to compute the
   %  Circular Polarized (CP) Co-Pol and X-Pol Gains of the AUT.
   %   The AUT CP Axial Ratio is also calculated

   %   %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
%   Use AC pair (Probe1-AUT) measurement

filename =deblank(HFnameABACBC(2,:));        %  Horizontal data
[Freq, HMAG, HPHASE, ERR_INDEX, IdentH]=wi_read(filename,'freq');
if ERR_INDEX ~= 0
   errmsg={['   ERROR  ' int2str(ERR_INDEX) ' reading file:  '];filename;...
         '';'    ABORTING'};
   errordlg(errmsg, errtitle);   errflg=1;   return, end

filename =deblank(VFnameABACBC(2,:));        %  Vertical data
[Freq, VMAG, VPHASE, ERR_INDEX, IdentV]=wi_read(filename,'freq');
if ERR_INDEX ~= 0
   errmsg={['   ERROR  ' int2str(ERR_INDEX) ' reading file:  '];filename;...
         '';'    ABORTING'};
   errordlg(errmsg, errtitle);   errflg=1;   return, end

%   Convert data to complex number. Set Eh and Ev as a 2-columns complex array

EhEv = [(10.^(HMAG/20)).*exp(j*HPHASE*pi/180) ...
        (10.^(VMAG/20)).*exp(j*VPHASE*pi/180)];

%   Calculate Er and El    (2-columns complex array)

ErEl = [EhEv(:,1) + j*EhEv(:,2) ...
        EhEv(:,1) - j*EhEv(:,2)]./sqrt(2);

ABSErEl = abs(ErEl);              %Absolute value array of Er and El (2-cols)

%   Calculate Axial Ratio:   AxialRatio  and AxialRatiodB

AxialRatio   = (ABSErEl(:,1) + ABSErEl(:,2))./ ...
             abs(ABSErEl(:,1) - ABSErEl(:,2));
AxialRatiodB = 20*log10(AxialRatio);

%   Select Co-Pol and X-Pol signal in CP, (get ABSErEl column index)

if sum(ABSErEl(:,1) > ABSErEl(:,2)) > length(FREQ)/2
   IndxCo = 1;   IndxX = 2;   Sense = ' RHCP ';     %IndxCo is column # for Co-Pol
else
   IndxCo = 2;   IndxX = 1;   Sense = ' LHCP ';     %IndxX  is column # for  X-Pol
end

disp(['AUT Polarization:                    ' AUTPol Sense]);
hm=helpdlg({['    ' AUTPol '  ' Sense]},'     AUT Polarization');
waitfor(hm)

%   %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%   Calculate CP Relative X-pol gain (CPrelXPgain  and CPrelXPgaindB)

CPrelXPgain   = abs(ErEl(:,IndxX)./ErEl(:,IndxCo)).^2;
CPrelXPgaindB = 10*log10(CPrelXPgain);

%   Calculate CP Co-Pol gain  (CPCoPgain and CPCoPgaindB)

CPCoPgain   = (10.^(TotalGain/10))./(1 + CPrelXPgain);
CPCoPgaindB = 10*log10(CPCoPgain);

%   calculate CP X-pol gain   (CPXPgaindB)

CPXPgaindB =  CPCoPgaindB + CPrelXPgaindB;
```

```
%   Pre-Assemble the output array   (ARrelXPGcpGxp)
%  (Axial Ratio, CP Relative X-Pol gain, CP Co-Pol gain, CP X-Pol gain)

ARrelXPGcpGxp = [ AxialRatiodB   CPrelXPgaindB   CPCoPgaindB   CPXPgaindB];

%   %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%  Plot CP Gain graphs

figure('position', [590 45 540 700], 'paperposition',[.5 .5 7.5 10]);
Subplot(2,1,1);                                 % Plot CP Co-pol and X-pol gains
plot (FREQ, ARrelXPGcpGxp(:, [3 4]));
axis([-inf inf -40 20]);hax=gca;
xlabel('Frequency in GHz');
ylabel('Gain in dB');
grid;
title(char(['AUT CP Gain    ' Sense '   (' NAMESABC(3,:) ')'], SUBTITLE), ...
   'buttondown', ['NwT=inputdlg({''Title'',''SubTitle''},''     Graph Title'',' ...
   '1,cellstr(get(gcbo,''string''))); if ~isempty(NwT) title(NwT), end'])
legend('Co-Pol','X-pol',2);

%  Put the experiment date on the graph (TEXT Box can be moved interactively)
xl=get(hax,'xlim'); yl=get(hax,'ylim');
ht=text(FREQ(1),yl(1),EXPDATE,'vert','bottom');
set(ht,'buttondown','pos=ginput(1);set(gcbo,''pos'',pos)')

subplot(2,1,2);                                 % Plot  CP Relative X-pol gains
plot(FREQ,ARrelXPGcpGxp(:,2));
title(char(['AUT  Relative X-Pol Gain   ', Sense], SUBTITLE), ...
   'buttondown', ['NwT=inputdlg({''Title'',''SubTitle''},''     Graph Title'',' ...
   '1,cellstr(get(gcbo,''string''))); if ~isempty(NwT) title(NwT), end'])
axis([-inf inf -50 10]);
xlabel('Frequency in GHz');
ylabel('Gain in dB');
grid;

%   %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% SAVING DATA TO FILE

[dfile,dpath] = uiputfile('*.txt','Save the CP AUT Gain Array to File');
if ~((size(dpath,2) == 1) & (size(dfile,2) == 1))
   fid = fopen([dpath,dfile],'wt');
   disp(['Output Array Filename:             ' dpath,dfile]);

   %      Header information

   fprintf(fid,'%s\n',  'Antenna Gain Measurement:         3-Antenna Method');
   fprintf(fid,'%s\n', ['SubTitle:                         ' SUBTITLE]);
   fprintf(fid,'%s\n', ['Date:                             ' EXPDATE]);
   fprintf(fid,'%s\n', ['Probe1 Name:                      ' Probe1Name]);
   fprintf(fid,'%s\n', ['Probe2 Name:                      ' Probe2Name]);
   fprintf(fid,'%s\n', ['AUT Name:                         ' AUTName]);

   fprintf(fid,'%s\n', ['AUT Polarization:                 ' AUTPol ' ' Sense]);

   fprintf(fid,'%s\n', ['Probe1-Probe2 Filename (Hor Pol): ' HFnameABACBC(1,:)]);
   fprintf(fid,'%s%s\n','VNA Identification:               ', HIdentAB');
   fprintf(fid,'%s\n', ['Probe1-AUT Filename (Hor Pol):    ' HFnameABACBC(2,:)]);
   fprintf(fid,'%s%s\n','VNA Identification:               ', HIdentAC');
   fprintf(fid,'%s\n', ['Probe2-AUT Filename (Hor Pol):    ' HFnameABACBC(3,:)]);
   fprintf(fid,'%s%s\n','VNA Identification:               ', HIdentBC');
```

```
        fprintf(fid,'%s\n', ['Probe1-Probe2 Filename (Ver Pol): ' VFnameABACBC(1,:)]);
        fprintf(fid,'%s%s\n','VNA Identification:              ', VIdentAB');
        fprintf(fid,'%s\n', ['Probe1-AUT Filename (Ver Pol):    ' VFnameABACBC(2,:)]);
        fprintf(fid,'%s%s\n','VNA Identification:              ', VIdentAC');
        fprintf(fid,'%s\n', ['Probe2-AUT Filename (Ver Pol):    ' VFnameABACBC(3,:)]);
        fprintf(fid,'%s%s\n','VNA Identification:              ', VIdentBC');

        fprintf(fid,'%s\n', ['Cable Thru Correction Filename:   ' ThruPath,ThruFname]);
        fprintf(fid,'%s%s\n','VNA Identification:              ', ThruIdent');

        if AttenPath~=0
           fprintf(fid,'%s\n', ['Attenuator Frequency Response Filename: ' ...
                 AttenPath,AttenFname]);
        fprintf(fid,'%s%s\n','VNA Identification:              ', AttenIdent');
        end

        fprintf(fid,'%s\n', ['Input Parameter Filename:         ' ParamPath
ParamFname]);

fprintf(fid,'%s\n', ['Probe1-Probe2 Distance:          ' num2str(DISTABACBC(1)) ' m']);
fprintf(fid,'%s\n', ['Probe1-AUT Distance:             ' num2str(DISTABACBC(2)) ' m']);
fprintf(fid,'%s\n', ['Probe2-AUT Distance:             ' num2str(DISTABACBC(3)) ' m']);

        %      Data output: assemble the output array

        GainARRAY= [FREQ HGainABC VGainABC ARrelXPGcpGxp];
        TitleRow =['  FREQ     HGainP1   HGainP2  HGainAUT    VGainP1   VGainP2' ...
                 '  VGainAUT  AxRatio   RelX-Pol  C-PGain   X-PGain   All in dB'];
        fprintf(fid,'%s\n', ['**' TitleRow]);
fprintf(fid,'%9.4f %9.4f %9.4f %9.4f %9.4f %9.4f %9.4f %9.4f %9.4f %9.4f %9.4f\n', ...
           GainARRAY');
        fclose(fid);
    end
end                          %      END Switch
```

getparam

```
%  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%  Local FUNCTION

%  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function [ParamValue, errflg]=getparam(fid, ParamType)
%  This routine reads ONE line from the input parameter file
%  it compares the parameter type read with "ParamType"
%  and output the corresponding parameter value ("ParamValue")
%
%  The parameter line is formatted as follows:
%
%  Parameter Type :  Parameter Value   (where the ":" acts as a delimiter)
%
%  If the parameter type:
%        °  is not found   or,
%        °  the format of the line is not as described above,  or
%        °  an EOF is encountered,
%  the output variable errflg=1, and
%  the parameter Value ("ParamValue") is empty
%
```

```
% Input args:
%                fid:       File ID
%          ParamType:       string representing the parameter type
% Output args:
%         ParamValue:       output string representing the parameter value
%             errflg:       errror flag = 0 for no error
%
% Programmed by Claude Brochu                Date:       Sept-Oct 1998
%
%
% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

errflg=0; ParamValue='';

ParamLine=fgetl(fid);                   % read a file record (line)
if ParamLine==-1 errflg=1
   msg={'EOF encountered                                  .';'';'ABORTING'};
   errordlg(msg,'ERROR: Reading Input Parameter File')
   return, end

[Type, Value]=strtok(ParamLine,':');    % Parse the type and value
if isempty(Value) errflg=1;
   msg={'NOT a Parameter Line                             .';'';'ABORTING'};
   errordlg(msg,'ERROR: Reading Input Parameter File'), return
elseif strcmp(lower(deblank(Type)), lower(deblank(ParamType)))
   ParamValue=deblank(Value(Value~=':'));
else
   errflg=1;
   msg={'WRONG Parameter Line Read                        .';'';'ABORTING'};
   errordlg(msg,'ERROR: Reading Input Parameter File'), return
end

% %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

gain3acalc

```
function [GainABC, FnameABACBC, IdentAB, IdentAC, IdentBC, errflg] = gain3acalc(Polflg)
% --------------------------------------------------------------------------
%  Gain Calculation Function
% --------------------------------------------------------------------------
%
%  input argument:
%           Polflg        Polarization flag {'L'|'H'|'V'}
%                         to indicate AUT pol Linear,
%                         AUT pol Circular/probes E-plane horizontal, or
%                         AUT pol Circular/probes E-plane vertical.
%  Output arguments:
%           GainABC       3-columns array of gains
%           FnameABACBC   3-rows, measurement filenames
%           Identnn       4-rows identification strings from the VNA (.dat) file
%           errflg        if == 1,      means errors encountered with files, or data
%                               such as frequency values are different
%                               it means also that a file selection was CANCELed
%                               so program aborts
%
%  This function calculates ANTENNA GAINs using the 3-antennas method.
%  Measurement data files are VNA Wiltron 360 tabular '*.dat' files
%
% --------------------------------------------------------------------------
%
%  The antennas are labelled as such:
%        Probe1    -> A
%        Probe2    -> B
%        AUT       -> C
%
%  So variables names terminated by 1, 2 Or 3 of these letters refer to
%  the respective antenna(s)
%
%%%%%%%%%%%%%%%%%%%%
% 3 ANTENNA METHOD %
%%%%%%%%%%%%%%%%%%%%
%
%  Theoritical Equation (from Antenna Course)
%
%  Formula for one antenna pair (AB) gain measurement
%
%  Ga + Gb = 20 Log (4 pi Rab/lambda) - 10 Log (Po/Pr)    or
%     "    =     "                    + 10 Log (Pr/Po)    or
%     "    =     "                    + VNA S21 AB Measurement (named AB)
%
%  where:
%  Rab:       Separation distances (in metres) between antennas for antenna pair AB
%  lambda:    wavelength (in metres)
%             = C/FREQ = .3/FREQ ,
%             where  C=0.3 and FREQ is the frequency in GHz
%  pi:        PI
%  Po:        input    power at source  antenna
%  Pr:        is received power at receive antenna
%
%  Ga + Gb = FactorAB                                       (1)
%
%  Solving for 3 antennas A, B, C measured in pairs in the order AB, AC, BC
%
%  2 GainA = FactorAB + FactorAC - FactorBC                 (2a)
%  2 GainB = FactorAB + FactorBC - FactorAC                 (2b)
```

```
%  2 GainC = FactorAC + FactorBC - FactorAB                     (2c)
%
%  FactorAB = 20 Log (4 pi Rab FREQ/c) + S21AB                  (3a)
%  FactorAC = 20 Log (4 pi Rac FREQ/c) + S21AC                  (3c)
%  FactorBC = 20 Log (4 pi Rbc FREQ/c) + S21BC                  (3c)
%
%  A correction "CORRECTION" must be substracted in equation (1), to take into
%  account, the loss in cables and RF circuitry from VNA ports to the antennas.
%  The correction which is the measured S21 of the complete RF circuit chain
%  less the antennas is computed by the calling program.
%
%  The correction is applied to the gain equation as shown below in  the listing
%
%
%  Programmed by Claude Brochu          Date:           Mar     1998
%                                      Revision 2:     Sep/Oct 1998
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

global FREQ DISTABACBC CORRECTION SUBTITLE NAMESABC EXPDATE

errflg = 0;
c = 0.3;                         % speed of light, scaled for the WL-Freq formula

DistAB = DISTABACBC(1);          % dist. between pairAB AEs in meters
DistAC = DISTABACBC(2);          % dist. between pairAC AEs in meters
DistBC = DISTABACBC(3);          % dist. between pairBC AEs in meters

MidTitle='Partial ';                      %  for graph title
figpos=[490 400 560 420;515 375 560 420]; %  graphs are cascaded

switch Polflg                    % set string qualifier for filename query
case 'L'
   AUTPol='LINEAR'; MidTitle='';
case 'H'
   AUTPol='HORIZONTAL';
case 'V'
   AUTPol='VERTICAL';
   figpos(:,[1 2])=[540 350;565 325];
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%  Get Data filenames

errmsg={'File Selection Cancelled';'';'ABORTING'};
errtitle='    File Selection';

msg=[AUTPol '  "Probe1-Probe2" File Selection'];
[ABfname ABpath]=uigetfile('*.dat', msg);
if ABfname==0        errordlg(errmsg, errtitle);   errflg=1;   return, end
disp([AUTPol ', Probe1-Probe2 Filename:   ' ABpath ABfname]);     cd(ABpath)

msg=[AUTPol '  "Probe1-AUT" File Selection'];
[ACfname ACpath]=uigetfile('*.dat', msg);
if ACfname==0        errordlg(errmsg, errtitle);   errflg=1;   return, end
disp([AUTPol ', Probe1-AUT Filename:      ' ACpath ACfname]);

msg=[AUTPol '  "Probe2-AUT" File Selection'];
[BCfname BCpath]=uigetfile('*.dat', msg);
if BCfname==0        errordlg(errmsg, errtitle);   errflg=1;   return, end
disp([AUTPol ', Probe2-AUT Filename:      ' BCpath BCfname]);
```

```
%  Assemble Filenames Array for output
FnameABACBC=char([ABpath,ABfname], [ACpath,ACfname], [BCpath,BCfname]);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%  Read Wiltron VNA tabular data files (*.DAT)

errtitle='Error Reading File';

%  Read (AB)   Probe1-Probe2 measurement data
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

[Freq, AB, PHASE, ERR_INDEX, IdentAB]=wi_read([ABpath,ABfname],'freq');
if ERR_INDEX ~= 0
   errmsg={['   ERROR  ' int2str(ERR_INDEX) '   reading file:']; ''; ...
         ['  ' ABpath,ABfname]; '';'  ABORTING'};
   errordlg(errmsg, errtitle);   errflg=1; return, end
disp(sprintf('%s%s','VNA Identification:                 ', IdentAB'))

if freqchk(Freq)==1 errflg=1; return, end     %   Frequency values different?

%  Read (AC)    Probe1-AUT measurement data
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

[Freq, AC, PHASE, ERR_INDEX, IdentAC]=wi_read([ACpath,ACfname],'freq');
if ERR_INDEX ~= 0
   errmsg={['   ERROR  ' int2str(ERR_INDEX) ' reading file:'];     ''; ...
         [ACpath,ACfname]; '';'  ABORTING'};
   errordlg(errmsg, errtitle);   errflg=1;   return, end
disp(sprintf('%s%s','VNA Identification:                 ', IdentAC'))

if freqchk(Freq)==1 errflg=1; return, end     %   Frequency values different?

%  Read (BC)    Probe2-AUT measurement data
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

[Freq, BC, PHASE, ERR_INDEX, IdentBC]=wi_read([BCpath,BCfname],'freq');
if ERR_INDEX ~= 0
   errmsg={['   ERROR  ' int2str(ERR_INDEX) ' reading file:'];     ''; ...
         [BCpath,BCfname]; '';'  ABORTING'};
   errordlg(errmsg, errtitle);   errflg=1;   return, end
disp(sprintf('%s%s','VNA Identification:                 ', IdentBC'))

if freqchk(Freq)==1 errflg=1; return, end     %   Frequency values different?

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%  GAIN CALCULATION

FactorAB = (20.*(log10((4*pi*DistAB/c).*FREQ))) + AB;% factor for AB equation
FactorAC = (20.*(log10((4*pi*DistAC/c).*FREQ))) + AC;% factor for AC equation
FactorBC = (20.*(log10((4*pi*DistBC/c).*FREQ))) + BC;% factor for BC equation

GainA = (FactorAB + FactorAC - FactorBC - CORRECTION)./2; % antenna A (Probe1)
GainB = (FactorAB + FactorBC - FactorAC - CORRECTION)./2; % antenna B (Probe2)
GainC = (FactorAC + FactorBC - FactorAB - CORRECTION)./2; % antenna C (AUT)

%  Assemble Gain Array for output
GainABC = [GainA GainB GainC];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
%  Plot the 3 gains
figure('pos',figpos(1,:));
set(gca,'pos',[1 1 1 .96].*get(gca,'pos'))     %  make room for SubTitle
plot(FREQ,GainABC)
axis([-inf inf -10 20]); hax=gca;
title(char([AUTPol, MidTitle, ' Gains: ' '3-Antenna Method'], SUBTITLE), ...
      'buttondown', ['NwT=inputdlg({''Title'',''SubTitle''},''     Graph Title'',' ...
      '1,cellstr(get(gcbo,''string''))); if ~isempty(NwT) title(NwT), end'])
leg1=['Probe1-'  deblank(NAMESABC(1,:))];
leg2=['Probe2-'  deblank(NAMESABC(2,:))];
leg3=['AUT    -' deblank(NAMESABC(3,:))];
legend(leg1,leg2,leg3,2)
xlabel('Frequency in GHz'); ylabel('Gain in dB'), grid

%  Put the experiment date on the graph  (TEXT Box can be moved interactively)
xl=get(hax,'xlim'); yl=get(hax,'ylim');
ht=text(FREQ(1),yl(1),EXPDATE,'vert','bottom');
set(ht,'buttondown','pos=ginput(1);set(gcbo,''pos'',pos)')

%  Max AUT Gain
[maxgain,maxfreq]=max(GainC);
msg=['Max AUT Gain (',Polflg,'): '];
msg1=[num2str(maxgain), ' dB at ',num2str(FREQ(maxfreq)),'GHz.'];
Title=['                Maximum AUT Gain (' ,Polflg,')'];
hg=helpdlg([msg msg1],Title); waitfor(hg)
disp([msg '                     ' msg1])

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% PLOT UNPROCESSED MEASURED DATA

ABname = ABfname(1:findstr(ABfname,'.')-1);   % use Filename in legend
ACname = ACfname(1:findstr(ACfname,'.')-1);
BCname = BCfname(1:findstr(BCfname,'.')-1);

figure('pos',figpos(2,:));
set(gca,'pos',[1 1 1 .96].*get(gca,'pos'))     %  make room for SubTitle
plot(FREQ,[AB AC BC])
axis([-inf inf -50 10]); hax=gca;
title(char('Measured Data: Antenna-Pairs',SUBTITLE), ...
      'buttondown', ['NwT=inputdlg({''Title'',''SubTitle''},''     Graph Title'',' ...
      '1,cellstr(get(gcbo,''string''))); if ~isempty(NwT) title(NwT), end'])
legend(ABname, ACname, BCname, 2)            %  use part. filenames as legend
xlabel('Frequency in GHz'); ylabel('Gain in dB'); grid;

%  Put the experiment date on the graph  (TEXT Box can be moved interactively)
xl=get(hax,'xlim'); yl=get(hax,'ylim');
ht=text(FREQ(1),yl(1),EXPDATE,'vert','bottom');
set(ht,'buttondown','pos=ginput(1);set(gcbo,''pos'',pos)')

pause(.5)       %  A delay seems necessary here to allow for the last graph
                %  to be displayed before returning to the calling program

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

freqchk

```
function     ferr = freqchk(freq)
%  This function compares the input argument <freq> with the global
%  variable FREQ
%  The output variable ferr = 1 if the comparison fails
%  ------------------------------------------------------------------------
%  check frequency values
%  ------------------------------------------------------------------------

%  Programmed by Claude Brochu                          Date: Mar 1998

global FREQ
ferr=0;
if length(FREQ)~=length(freq)
   ferr=1;
    elseif sum(FREQ==freq)~=length(freq)
   ferr=1;
    end

if ferr==1
   msg={'';'   ERROR  -  Frequency Values Different';'';'   ABORTING'};
   title='    Frequency Values CHECK';
   errordlg(msg,title);
   return;
end;

%  %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

wi_read

```
function [freq_dist,mag,phase,err_index,ident] = wi_read (filename,domain)
%
%      WI_READ  reads a WILTRON data file with only one channel data.
%      The Wiltron file can be in frequency or time domain.
%      [FREQ_DIST, MAG, PHASE, ERR_INDEX, IDENT] = WI_READ (FILENAME, DOMAIN)
%        FREQ_DIST  :  frequency in GHz or distance in meters
%        MAG        :  magnitude in dB
%        PHASE      :  phase in degrees
%        ERR_INDEX  :  0  no error
%                      1  DOMAIN string is invalid
%                      2  file could not be opened
%                      3  file is not in a recognized Wiltron format
%                      4  file is not in the domain specified
%        IDENT      :  4 identification strings in VNA output form
%        FILENAME   :  file name including path
%        DOMAIN     :  'freq' or 'time' for frequency or time domain.
%
%      See also:     .
%
%      Written by GAM, 7 Feb. 1996.
%
%      Modified by CJB, 4 Dec 1997, Jan 98, Apr 98
%
%  In this revision there is no skips at the beginning, the String:
%  "360 NETWORK ANALYSER"  IS SEARCHED TO DETERMINE IF IT IS A VNA FILE
%
%    Four identfication strings from the VNA output form are stored in
%  a character matrix of size [4, 13]
%
%  The  internal variables are initialized now
%
% I cannot initialize the output arrays because of the way they were programmed.
% It might be useful to vectorize this reader.
% I have assumed that time domain data is in distance and the units are m.,cm., or mm.
% If this is not the case, an error will be generated.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Set error index to 0 for no error.
err_index=0;

% Check input parameter: domain

if ~strcmp(domain,'freq') & ~strcmp(domain,'time')
   disp('---$$!$$--- The ''domain'' value is unknown')
    err_index=1;
   return
end

% Get fid.
[fid,message]=fopen(filename);
if fid==-1
  disp( '---??!??--- The following file could not be opened:')
  disp(['---??!??--- ' filename])
  disp(['---??!??--- ' message])
  err_index=2;
  return
end

%Search for Wiltron 360 Header
```

```
for I = 1:10
   dummy=fgetl(fid);
   if length(dummy)==20
      if dummy=='360 NETWORK ANALYZER' break ; end;
   end
end

if I==11 err_index=3; fclose(fid); return; end        %      Should have found
dummy=fgetl(fid);                                     %      already the VNA label

%  Read Data Identification from Wiltron output Form

label=fgetl(fid);
if isempty(findstr(label,'MODEL:'))
   err_index=3; fclose(fid); return; end

ident=char(label(22:34),label(47:59));                         % Model , Date
label=fgetl(fid);
ident=char(ident,label(11:23),label(36:length(label)));       % Device ID, Operator

dummy=fgetl(fid); dummy=fgetl(fid);

%Read START, STOP, and STEP.

label=fgetl(fid);
if label(1:6)~='START:' err_index=3; fclose(fid); return; end
freq_start=sscanf(label(7:19),'%f',1);  %disp({'freq_start',freq_start})
label=fgetl(fid);
if label(1:6)~='STOP :' err_index=3; fclose(fid); return; end
freq_stop=sscanf(label(7:19),'%f',1);   %disp({'freq_stop',freq_stop})
label=fgetl(fid);
if label(1:6)~='STEP :' err_index=3; fclose(fid); return; end
del_freq=sscanf(label(7:19),'%f',1);     %disp({'del_freq',del_freq})
Nfreq=round((freq_stop-freq_start)/del_freq+1);      %disp({'Nfreq',Nfreq})

% Identify what type of file it is.
for I=1:8, dummy=fgetl(fid); end;
while 1
  header=fgetl(fid);
  if ~isstr(header)
    disp('---$$!$$--- End-of-file was encountered unexpectedly.')
    err_index=3;
    fclose(fid);
    return
  end
  if length(header)==17
     if header=='FREQUENCY POINTS:'
        if domain~='freq'
           disp('---$$!$$---The input file is in frequency domain but time domain was
requested.')
           err_index=4;
           fclose(fid);
           return
        end
        td_flag=0;
        break
     end
  elseif length(header)==16
     if header=='DISTANCE POINTS:'
        if domain~='time'
           disp('---$$!$$---The input file is in time domain but frequency domain was
requested.')
```

```
            err_index=4;
            fclose(fid);
            return
         end
         td_flag=1;
         break
      end
   end
end
for I=1:4, dummy=fgetl(fid); end;

%  initialize Variables

    index = [];    freq  = [];    mag   = [];    phase = [];    dist={};

% Read all table data (freq. domain or time domain)
if ~td_flag
  for I=1:12,
    [parms,count] = fscanf(fid,'%f',[4,48]);
    if count==0 break, end
    index = [index ; parms(1,:)'];
    freq  = [freq  ; parms(2,:)'];
    mag   = [mag   ; parms(3,:)'];
    phase = [phase ; parms(4,:)'];
    for I=1:9, dummy=fgetl(fid); end
  end
else
  eof=0;
  while ~eof
    [parms,count] = fscanf(fid,'%f');
    if count~=2 disp('---??!??--- Error 1001'), count, parms, break, end
    index = [index ; parms(1)];
    dist  = [dist  ; parms(2)];
    while 1
      [parms,count] = fscanf(fid,'%s1');
      if strcmp(parms,'m')

      elseif strcmp(parms,'cm')
        dist(length(dist))=dist(length(dist))*0.01;
      elseif strcmp(parms,'mm')
        dist(length(dist))=dist(length(dist))*0.001;
      else
        disp('---??!??--- Error 1003')
        return
      end
%
      [parms,count] = fscanf(fid,'%f');
      if count==4
        mag   = [mag   ; parms(1)];
        phase = [phase ; parms(2)];
        index = [index ; parms(3)];
        dist  = [dist  ; parms(4)];
      elseif count==2
        mag   = [mag   ; parms(1)];
        phase = [phase ; parms(1)];
        break
      else
        disp('---??!??--- Error 1002')
      end
    end
    for I=1:9
      dummy=fgetl(fid);
      if ~isstr(dummy) eof=1; break, end
```

```
    end
  end
end
fclose(fid);

if ~td_flag
% Must remove extra frequencies if added by markers.
  if length(freq)> Nfreq
    if freq(1)~=freq_start disp('First frequency is unexpected'); return, end
    if freq(length(freq))~=freq_stop disp('Last frequency is unexpected'); return, end
    error_count=0;
    skip=0;
    for I=2:length(freq),
      if skip==0
        if (freq(I)-freq(I-1)) < del_freq-0.00001
          error_count=error_count+1;
          error_index(error_count)=I;
          skip=1;
        end
      else
        skip=0;
      end
    end
    if length(freq)-error_count ~= Nfreq
      disp('The frequency spacing is not right.')
      disp('Check the following frequency indexes for bad frequencies:')
      disp(error_index)
    else
      mask=ones(length(freq),1);
      for K=1:error_count,
        mask(error_index(K))=0;
      end
      freq =freq (mask);
      mag  =mag  (mask);
      phase=phase(mask);
    end
  elseif length(freq) < Nfreq
%     disp(['WARNING: Received from the VNA ' num2str(length(freq)) ' data points
instead of the ' ...
%           num2str(Nfreq) ' expected'])
  end
  freq_dist=freq;
else
% Must remove extra distances if added by markers.
% I am not sure any distances are added but in case I am checking that all
% delta-distances are within 1/100 of each others.
  delta_dist=dist(2:length(dist))-dist(1:length(dist)-1);
  max_del=max(delta_dist);
  min_del=min(delta_dist);
  mean_del=mean(delta_dist);
  if (max_del-min_del)*100>mean_del
    disp('---??!??--- The distances are not evenly spaced as expected')
    max_del
    min_del
    mean_del
  end
  freq_dist=dist;
end
```

Function ascanf

```
function  [array, count] = ascanf(skip,prntskip)
%  This function reads a numerical array from a file
%
%     skip : optional input argument, it has two meanings
%           1.     it is the number of lines to skip before reading numerical data,or
%           2.     it is a text string to search for. This string should be a
%                  unique string to be found in the last header record before
%                  the start of the data array.  The file pointer is positioned
%                  after the record containing the skip string. It should point
%                  to the first line of numerical data
%
%     prntskip:    if argument exist,  print skipped lines if 'skip' is a string
%
%  N.B. with no input argument the file must contain only an array of numbers
%             please be careful no checks are made
%
%     Array  :     the data array read
%     count  :     the total no of data in the array
%
%     Method:
%  A request in made for the file name to read
%  Records are skipped as requested
%  The first row of data is read to determined the number of columns
%  The data are read and column formatted
%  This function do not read  ',' delimited data
%
%  Claude Brochu                 Date:  16 Jan 1998   revised:     25 Feb 1998
%                                                                  24 mar 1998
%  ---------------------------------------------------------------
[fname fpath] = uigetfile('*.txt','Enter Array filename');
if fname == 0 return, end;                                %     CANCEL selected
disp([fpath fname]);
fid = fopen([fpath fname]);

%  Skip when required

if nargin > 0 & ~isempty(skip)
   if isstr(skip)
       while 1
              str=fgetl(fid); if nargin==2 disp(str), end
              if ~isempty(findstr(str,skip))
                    if nargin==1 disp(str),end
               break,      end
       end
   else
       for i=1:skip
          dumy = fgetl(fid);
      end
   end
end

%  Find No of columns

frstrow = sscanf(fgetl(fid),'%g');
NC = length(frstrow);                     %      No of columns

[array count] = fscanf(fid ,'%g',[NC inf]);
array=[frstrow';array'];                  %      Format array
count=count + NC;
fclose (fid);
```

UNCLASSIFIED

SECURITY CLASSIFICATION OF FORM
(highest classification of Title, Abstract, Keywords)

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Establishment sponsoring a contractor's report, or tasking agency, are entered in section 8.)

Defence Research Establishment Ottawa
Ottawa, Ontario
K1A 0Z4

2. SECURITY CLASSIFICATION (overall security classification of the document including special warning terms if applicable)

UNCLASSIFIED

3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C or U) in parentheses after the title.)

Gain Measurement of a Cavity-Backed Spiral Antenna From 4 to 18 GHz Using the Three-Antenna Method (U)

4. AUTHORS (Last name, first name, middle initial)

Brochu, Claude J., Morin, Gilbert A., Moffat, John, W.

5. DATE OF PUBLICATION (month and year of publication of document)

November 1998

6a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.)

49

6b. NO. OF REFS (total cited in document)

5

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.

DREO Report

8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include the address.

EHF SATCOM, Electronics Division, Defence Research Establishment Ottawa
Ottawa, Ontario, K1A 0Z4

9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant)

Project 5CA12

9b. CONTRACT NO. (if appropriate, the applicable number under which the document was written)

10a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.)

DREO REPORT 1337

10b. OTHER DOCUMENT NOS. (Any other numbers which may be assigned this document either by the originator or by the sponsor)

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)

(X) Unlimited distribution
( ) Distribution limited to defence departments and defence contractors; further distribution only as approved
( ) Distribution limited to defence departments and Canadian defence contractors; further distribution only as approved
( ) Distribution limited to government departments and agencies; further distribution only as approved
( ) Distribution limited to defence departments; further distribution only as approved
( ) Other (please specify):

12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). however, where further distribution (beyond the audience specified in 11) is possible, a wider announcement audience may be selected.)

Unlimited Announcement

13. ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

This report presents the results of the measurement of the maximum gain of a cavity- backed spiral antenna in the frequency range of 4-18 GHz. This measurement activity was requested by CFEWC. The method selected for this measurement was the three-antenna method for antenna gain measurements. As the antenna-under-test (AUT) is a circularly polarized (CP) antenna, the method was extended to obtain the CP co-pol and cross-pol gain of the AUT. This method requires the use of two other linearly polarized (LP) antennas. Two sets of gain measurements were performed using the LP antennas with their polarization oriented horizontally and then vertically. The two antennas were TECOM LP quad-ridged horns. Although these horns are dual polarized, only one polarization was used. This report describes also the three-antenna method algorithm, the Matlab program written for this application, and gives an outlook of the experimental steps and procedures required to implement the method.

The antenna gain measurements were made in the far-field antenna measurement range in the DREO-DFL Antenna Research Laboratory (DDARLing).

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

Antenna gain measurement, Three-antenna method